The journal of
PROSTHETIC AND IMPLANT DENTISTRY
Official Publication of Indian Prosthodontic Society
Kerala State Branch
jpid.ipskerala.com

NANOTECHNOLOGY IN PROSTHODONTICS – A REVIEW

* Fayiz S Faizal, * Aiswarya R Nair, * Greeshma Prakash,
** Sudeep S., *** Sheeba Gladstone, **** Manoj Prasad PG

* P.G. Student, ** Principal, HOD and Professor, ***Assistant Professor, ****Senior Lecturer, Dept of Prosthodontics, PMS College of Dental Science and Research, Vattappara, Trivandrum | Corresponding Author: Dr. Fayiz S Faizal, Email: sfaizalfayiz@gmail.com

https://doi.org/10.55231/jpid.2022.v05.i03.06

Introduction

Nanotechnology is the emerging science of technology that deals with the study and application of nano sized materials (10-9 mm) that can be used in various engineering and medical fields. Nanodentistry is the field of science and technology that deals with the diagnosing, treating and preventing oral and dental diseases, relieving pain, maintaining and improving dental health using nano particles. In future, nanodentistry will succeed in maintaining near-perfect oral health through the aid of nanorobotics and nanomaterials. The new era of dental treatment emphasis on nanomedicine, nanorobotics, nanodiagnostics, nanodental materials, nanosurgery and nanodrugs. Nanodentistry may seem more science fiction than fact, but with current advancements in science, technology, and medicine, it may very well be a reality in the distant future. It is important to assess the biocompatibility of nanostructures prior to their use in dentistry to avoid possible pathological conditions. Social challenges like ethical problems and public acceptance are of major concern. The article aims to bring forth and highlight the most recent and innovative research outcomes leading to the application of nanotechnology in the field of dentistry.

Materials and Methodology

A literature search was done by using the key words "nanodentistry" "nanotechnology" "nanoparticles in dentistry" "application of nanotechnology in prosthodontics". The reference articles were taken from pubmed indexed journals. The full text articles were obtained. The article focused on nanotechnology in prosthodontics. Only articles that were published in English were included

Review of literature

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.[1] 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.[2] 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.[3,4] Antimicrobial activities of titanium dioxide against candida albicans, staphylococcus aureus, pseudomonas aeruginosa, escherichia coli, lactobacillus acidophilus, etc. have been proved by recent studies.[5-8] Along with prominent catalytic effect, other characteristics such as white color, low toxicity, high stability and efficiency as well as availability have made titanium dioxide an appropriate antimicrobial additive for use in acrylic resin.[9,10] 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.[11]

SILVER NANOPARTICLES due to their small size possess greater dispersion in PMMA matrix and produce larger area for oxidation.[12]

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.[13]

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.[14]

Studies reported that silver nanoparticles are cytotoxic to different cell lines.[15]

Results showed that silver nanoparticles were cytotoxicity in the case of exposure at high concentrations.[16]

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.[17]

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.[18]

Impressions

Nanofillers are integrated in vinylpolysiloxanes, producing a unique addition of siloxane impression materials.[19] The material has better flow, improved hydrophilic properties hence fewer voids at margin and better model pouring, and enhanced detail precision. Advantages includes Increased fluidity, High tear resistance, Hydrophilic properties, Resistance to distortion and heat resistance, Snap set that consequently reduces errors caused by micro movements. Trade name is Nanotech Elite H-D

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.[20] Tissue conditioners could be kept clean

by mechanical and chemical methods but this can cause considerable damage to tissue conditioners.[21,22] Silver has been well known for its antimicrobial characteristic.[23] 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.[24]

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 are added to dental adhesives[25]. 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.[26]

Composites

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.[27] 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 are good optical properties., dispersion rate is improved, increased polish retention and increased surface gloss

Disadvantages are poor rheological properties and 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[28] as well as from mixed oxides of silica and zirconia have been synthesized.[29]

Advantages are good optical properties, Dispersion rate is improved, Increased polish retention, Increased surface gloss and Rheological properties better than the previous one.

Disadvantages is 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.[30]

Advantages are improved esthetic properties and Improved rheological properties

Disadvantages are decreased Dispersion rate and 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 organosilaneallyltriethoxysilane (ATES) are used in order to improve the microhardness and flexural strength of the resin-based composites.[31] 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.[32]

4. **Nanocomposite with Alumina Nanoparticles** - According to study conducted by M. AlHaik 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.[33] 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.[34]

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.[35] 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 dicalcium phosphate nanoparticles incorporated in composites.[36] 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.[37]

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. [38]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.[39,40] Silver nanoparticles are used because of their advantage that they show strong antibacterial activity due to their higher surface area to volume ratio.[41] 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.[42]

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.[31]

Tokushifujieda 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.[43]

Implants

New coating technologies have also been developed for applying hydroxyapatite and related calcium phosphates (CaP), the mineral of bone onto the surface of implants.

Many studies have demonstrated that these CaP coatings provided titanium implants with an osteoconductive surface.[44,45] Following implantation, the dissolution of CaP coatings in the periimplant region increased ionic strength and saturation of blood leading to the precipitation of biological apatite nanocrystals onto the surface of implants. This biological apatite layer incorporates proteins and promotes the adhesion of osteoprogenitor cells that would produce the extracellular matrix of bone tissue

It has been also shown that osteoclasts, the bone resorbing cells, are able to degrade the CaP coatings through enzymatic ways and created resorption pits on the coated surface.[45]

Finally, the presence of CaP coatings on metals promotes an early Osseo integration of implants with a direct bone bonding as compared to non-coated surfaces.

The challenge is to produce CaP coatings that would dissolve at a similar rate than bone apposition in order to get a direct bone contact on implant surfaces

Maxillofacial Prosthesis

Pesqueira et al evaluated the effect of disinfection and accelerated ageing on the dimensional stability and detail reproduction of a facial silicone with different types of nanoparticle. A total of 60 specimens were fabricated with Silastic MDX 4-4210 silicone and they were divided into three groups: colorless and pigmented with nanoparticles (make-up powder and ceramic powder). Half of the specimens of each group were disinfected with Efferdent tablets and half with neutral soap for 60 days. Afterwards, all specimens were subjected to accelerated ageing. Both dimensional stability and detail reproduction tests were performed, after specimen fabrication (initial period), after chemical disinfection and after accelerated aging periods (252, 504 and 1008 hours). The dimensional stability test was conducted using AutoCAD software, while detail reproduction was analyzed using a stereoscope magnifying glass. Dimensional stability values were statistically evaluated by analysis of variance (ANOVA) followed by Tukey's test ($p < 0.01$). Detail reproduction results were compared using a score. Chemical disinfection and also accelerated ageing affected the dimensional stability of the facial silicone with statistically significant results. The silicone's detail reproduction was not affected by these two factors regardless of nanoparticle type, disinfection and accelerated ageing.[46]

Discussion

The uses of various nanoparticles in acrylic resin, tissue conditioner, dental adhesives, composites, dental cements, dental porcelain, implants and maxillofacial prosthesis are discussed. 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 na-

noparticles

7. For implants - nanostructured hydroxyapatite and Nano porous alumina

8. For maxillofacial prosthesis - silver, titanium dioxide and cerium dioxide nanoparticles.

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. 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.

Conclusion

Nanomaterials and nanorobots are of great interest when considering advances in nanotechnology. Although all the research activities for this promising field are at the initial stage, the results of the clinical studies have a strong potential to revolutionize the diagnosis and treatment planning as well as tissue regenerative materials for improving esthetics in dental field.

However more investigations and clinical trials are required for the application of nanotechnology in oral health and dental care.

References

1. Price CA. A history of dental polymers. AustProsthodont J 1994;8:47-54. 10.
2. Lessa FC, Enoki C, Ito IY, Faria G, Matsumoto MA, Nelson-Filho P. In vivo evaluation of the bacterial contamination and disinfection of acrylic baseplates of removable orthodontic appliances. Am J OrthodDentofacialOrthop 2007;131:705:11-1.
3. Su W, Wei SS, Hu SQ, Tang JX. Preparation of TiO2/Ag colloids with ultraviolet resistance and antibacterial property using short chain polyethylene glycol. J Hazard Mater 2009;172:716-20.
4. Yao Y, Ohko Y, Sekiguchi Y, Fujishima A, Kubota Y. Self-sterilization using silicone catheters coated with Ag and TiO2 nanocomposite thin film. J Biomed Mater Res B ApplBiomater 2008;85:453-60.
5. Wan Y, Zhang D, Wang Y, Qi P, Wu J, Hou B. Vancomycin-functionalised Ag@TiO2 phototoxicity for bacteria. J Hazard Mater 2011;186:306-12.
6. Maneerat C, Hayata Y. Antifungal activity of TiO2 photocatalysis against penicilliumexpansum in vitro and in fruit tests. Int J Food Microbiol 2006;107:99-103.
7. Choi JY, Kim KH, Choy KC, Oh KT, Kim KN. Photocatalytic antibacterial effect of TiO2 film formed on Ti and TiAg exposed to lactobacillus acidophilus. J Biomed Mater Res B ApplBiomater 2007;80:353-9.
8. Ohko Y, Utsumi Y, Niwa C, Tatsuma T, Kobayakawa K, Satoh Y, et al. Selfsterilizing and self-cleaning of silicone catheters coated with TiO2 photocatalyst thin films: a preclinical work. J Biomed Mater Res 2001;58:97-101.
9. Mu R, Xu Z, Li L, Shao Y, Wan H, Zheng S. On the photocatalytic properties of elongated TiO2 nanoparticles for phenol degradation and Cr(VI) reduction. J Hazard Mater 2010;176:495-2.
10. Pant HR, Pandeya DR, Nam KT, Baek WI, Hong ST, et al. Photocatalytic and antibacterial properties of a TiO2/nylon-6 electrospun nanocomposite mat containing silver nanoparticles. J Hazard Mater 2011;189:465-71.
11. Matsunami N, Hosono H. Colloid formation effects on depth profile of implanted Ag in SiO2 glass. ApplPhysLett 1993;63:2050-2.
12. Shekhar A, Soumyo M, Suparna M. Immobilized silver nanoparticles enhance contact killing and show highest e□cacy: elucidation of the mechanism of bactericidal action of silver. Nanoscale 2013;5:7328-40.
13. Douglas RM, Luiz FG, Aline ST, Emerson R. The growing importance of materials that prevent microbial adhesion: antimicrobial effect of medical devices containing silver. Int J of Antimicrobial Agents 2009;34:103-10.
14. Damm C, M¨unstedt H. Kinetic aspects of the silver ion release from antimicrobial polyamide/silver nanocomposites. ApplPhys A 2008;91:47986.
15. Fan C, Chu L, Rawls HR, Norling BK, Cardenas HL, Whang K. Development of an antimicrobial resin - A pilot study. Dent Mater 2011;27:322-28.
16. Chaloupka K, Malam Y, Seifalian A.M. Nanosilver as a new generation of nanoproduct in biomedical applications. Trends Biotechnol 2010;28:580-88.
17. Miura N, Shinohara Y. Cytotoxic effect and apoptosis induction by silver nanoparticles in HeLa cells. BiochemBiophys Res Commun 2009;390:73337.
18. Kvitek L, Panacek A, Prucek R, Soukupova J, Vanickova

M, Kolar M, et al.Antibacterial activity and toxicity of silver - Nanosilver versus ionic silver. J PhysConfSer 2011;304:012-29

19. Aeran-et-al. Nanodentistry:Is just a fiction or future. journal of oral biology and craniofacial research 5(2015)207–211.
20. Douglas RM, Luiz FG, Aline ST, Emerson RC, Adhemar CRF, Debora BB. Silver distribution and release from an antimicrobial denture base resin containing silver colloidal nanoparticles. J Prosthodont 2012;21:7-15.
21. Okita N, Orstavik D, Orstavik J, Ostby K. In vivo and in vitro studies on soft denture materials: microbial adhesion and tests for antibacterial activity. Dent Mater 1991; 7:155-60.
22. Harrison A, Basker RM, Smith IS. The compatibility of temporary soft materials with immersion denture cleansers. Int J Prosthodont 1989; 2:254-8.
23. Nikawa H, Iwanaga H, Hamada T, Yuhta S. Effects of denture cleansers on direct soft denture lining materials. J Prosthet Dent 1994;72:657-62.
24. Fu J, Ji J, Fan D, Shen J. Construction of antibacterial multilayer films containing nanosilver via layer-by-layer assembly of heparin and chitosansilver ions complex. J Biomed Mater Res A 2006;79:665-74.
25. Ki-Young Nam. In vitro antimicrobial effect of the tissue conditioner containing silver nanoparticles. J AdvProsthodont 2011; 3:204.
26. Silikas N, Masouras K, Satterthwaite J, Watts DC. Effects of nanofills in adhesives and aesthetic properties of dental resin composites. Int J Nano Biomater 2007;1(2):116-27.
27. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc 2003;134(10):1382-90.
28. Wu D, Kolb BU, Mitra SB, Craig BD, Holmes BN, Rusin RP, et al. Dental compositions containing nanofillers and related methods. US patent 7 2008;393:882.
29. Windisch MS, Zhang X, Rusin RP, Mitra SB. Clustered particle dental fillers. US patent 6 2004; 730:156.
30. CRA Foundation Newsletter. Clinicians' guide to dental products and techniques, understanding current resin-based composites relative to filler. 2007; 31(10):12.
31. Yang X, Feimin Z, Haifeng X, Ning G. Nanoparticle-reinforced resin-based dental composites. J Dent 2008; 36:450-55.
32. Polizos G, Tuncer E, Sauers I, James DR, Ellis AR, More KL. Electrical and mechanical properties of titanium dioxide nanoparticle filled epoxy resin composites, Advances in cryogenic engineering, transactions of the cryogenic engineering materials conference. ICMC 2010; 56.
33. Al-Haik M, Hanson C, Luhrs C, Tehrani M, Phillips J, Miltenberger S. Mechanical performance of dental fillers based on alumina nanoparticles Proc SEM Ann Conf 2009;1-4.
34. Zhanhu G, Tony P, Oyoung C, Ying W, Hahn HT. Surface functionalized alumina nanoparticle filled polymeric nanocomposites with enhanced mechanical properties. J Mater Chem 2006;16:2800-08.
35. Vollenweider M, Brunner TJ, Knecht S, Grass RN, Zehnder M, Imfeld T, Stark WJ. Remineralization of human dentin using ultrafine bioactive glass particles. ActaBiomater 2007;3(6):936-43.
36. Xu HHK, Weir MD, Sun L. Nanocomposites with Ca and PO4 release, effects of reinforcement, di-calcium phosphate particle size and silanization. Dent Mater 2007;23(12):1482-91.
37. Li L, Pan H, Tao J, Xu X, Mao C, Gu X, Tang R. Repair of enamel by using hydroxyapatite nanoparticles as the building blocks. J Mater Chem 2008;18(34):4079-84.
38. Daugela P, Oziunas R, Zekonis G. Antibacterial potential of contemporary dental luting cements. Stomatologija 2008;10(1):16-21.
39. Monteiro DR, Gorup LF, Takamiya AS, Ruvollo-Filho AC, Camargo ERD, Barbosa DB. The growing importance of materials that prevent microbial adhesion: antimicrobial effect of medical devices containing silver. Int J Antimicrobial Agents 2009;34(2):103-10.
40. Sintubin L, De Gusseme B, Van Der Meeren P, Pycke BFG, Verstraete W, Boon N. The antibacterial activity of biogenic silver and its mode of action. ApplMicrobio Biotech 2011;91(1):153-62.
41. Morones JR, Elechiguerra JL, Camacho A. The bactericidal effect of silver nanoparticles. Nanotechnology 2005;16(10):2346-53.
42. Yoshida K, Tanagawa M, Matsumoto S, Yamada T, Atsuta M. Antibacterial activity of resin composites with silver containing materials. Euro J Oral Sci 1999;107(4):29096
43. 43. Mitsunori U, Masakazu K, Nobukazu W, Yutaka D. Effects of adding silver nanoparticles on the toughening of dental porcelain. J Prosthet Dent 2013;109(4):24147.
44. 44. Geesink RG. Osteoconductive coatings for total joint arthroplasty. ClinOrthopRelat Res 2002; 395:53–65.
45. 45. Leeuwenburgh S, Layrolle P, Barrère F, De Bruijn J, Schoonman J, van Blitterswijk CA, et al. Osteoclastic resorption of biomimetic calcium phosphate coatings in vitro. J Biomed Mater Res 2001; 56(2):208–15
46. 46. Habekost LV, Camacho GB, Lima GS, Ogliari FA, Cubas GB, Moraes RR. Nanoparticle Loading Level and Properties of Experimental Hybrid Resin Luting Agents. J Prosthodont 2012; 21 (7): 540– 545.