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International Journal of Current Research
Vol. 10, Issue, 01, pp.64162-64166, January, 2018

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

NANOTECHNOLOGY – A NEW ERA IN PROSTHETIC DENTISTRY

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ARTICLE INFO

Article History:
Received 19th October, 2017
Received in revised form
11th November, 2017
Accepted 21st December, 2017
Published online 19th January, 2018

Key words:
Nanotechnology, Nanodentistry, Nanoparticles, Prosthodontics.

ABSTRACT

Human quest for knowledge has led us to myriad of innovations in the field of science to that extent that the future era is of nanotechnology. Nanotechnology is an emerging field of science dealing with the research at the nanoscale. It has been shown that the performances of many biomaterials used in prosthodontics have been significantly enhanced after their scales were reduced by nanotechnology, from micron-size into nanosize. On the other hand, many nanocomposites composed of nanomaterials and traditional metals, ceramics, resin or other matrix materials have been widely used in prosthodontics because their properties, such as modulus of elasticity, surface hardness, polymerization shrinkage and filler loading were significantly improved after the addition of the nanomaterials. This article aims to review all the applications of nanotechnology in the prosthodontics.

Citation: Dr. J. R. Gade, Dr. Ashish Naik, Dr. Vandana Gade, Dr. Prajakta Thool and Dr. Aushili Mahule, 2018. "Nanotechnology – A new era in prosthetic dentistry", *International Journal of Current Research*, 10, (01), 64162-64166.

INTRODUCTION

Prosthodontics is mainly concerned with the escalation of patient's social and mental well-being by improvinghis form, function and esthetics. This branchaims to restore the dental tissue defects by removable or fixed prostheses, also including the use of artificial substitute for maxillofacial tissue defects. An American physicist Dr. Richard Phillips Feynman elaborated the concepts of nanoscience and nanotechnology in 1959. Whereas the term "Nanotechnology" was first used in 1974 by Professor Taniguchi. Thereafter, lot of research and development has been made in the field of Nanotechnology. Nanotechnology is the engineering of functional systems at the molecular scale. It is mainly consists of processing, separation, consolidation and deformation of materials by one atom or one molecule. By convention, nanotechnology is taken as the scale range 1 to 100 nm. One nanometer is a unit of length that is equal to 1 billionth of a meter. Development of nanomaterials has greatly enriched the field of research in materials science including biomaterials. As the understanding of natural biological material properties and microstructure at nanoscale is gradually deepening, the role of nanomaterials in biomedical material science is more important (Freitas, 2000). Nanomaterials have been developed promptly and some researches of nanomaterials have been carried out on prosthodontics. Many of the current dental materials are available through nanocrystallization to improve their original performance and play continuously key role in oral applications. Research of nanotechnology in dental materials is mainly focused on two ways: one is the preparation of new inorganic nanoparticles, and the other is to modify the surface with inorganic nanofillers. Thereby improving the properties such as modulus of elasticity, surface hardness, polymerization shrinkage and filler loading were enhanced by the addition of nanomaterials. Thus the purpose of this article is to review the applications of nanotechnology in prosthodontic materials including impression materials, composites, ceramics, resins and applications in maxillofacial prosthodontics and Implantology.

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Applications of nanotechnology in prosthodontics

Impression materials

Dental impressions inevitably come in contact with the patient's saliva, blood and bacterial plaque, which carry pathogenic microorganisms. Contaminated impressions are a source of cross infection and transmitters of diseases to the dental staff and laboratory personnel. Therefore, sanitizing the impressions effectively before transportation to the dental laboratory becomes indispensable. But, conventional spray and the immersion disinfection of impression materials may lead to dimensional changes. So, Silver nanoparticles has been incorporated into irreversible hydrocolloid impression materials as antimicrobial agents without affecting their properties adversely. (Stoimenov *et al*., 2002) The impression material also requires properties like adequate flow, setting rate, elasticity, tearstrength, detail reproducibility and dimensional stability for better clinical results for fixed dental prosthesis. Polyvinylsiloxane impression material modified with nano-sized fumed silica, shows improved physical properties of impression material like-better flow, improved hydrophilic properties so having fewer voids and enhanced precise detailing. (Choi *et al*., 2011)

Nanocomposites

The increasing interest in esthetic restorations in recent years has led to further development of materials that have the same color as that of teeth. Nanotechnology has enabled the production of nano-dimensional filler particles, which are added either singly or as nanoclusters into composite resins. (Papadogiannis *et al*., 2008) Nanotechnology allows the production of nano-sized filler particles that are compatible with dental composites; therefore, a greater amount of filler can be added into the composite resin matrix. (Jung *et al*., 2007) Nanoparticles allow the production of composites with a smooth surface after the polishing process and provide superior esthetic features to the material. (Yesil *et al*., 2008) Composite resins containing such particles are easy to shape and have a high degree of strength and resistance to abrasion. The fillers in nanocomposites have higher translucency since they are smaller than the wavelength of light, allowing the generation of more esthetic restorations with a vast range of color options. (Mitra *et al*., 2003) Several reports have indicated that significantly smoother surfaces were achieved using composites with nanofiller compared to other composites this is because nanocomposites have much smaller sizes and contain much higher amounts of filler. (Joniot *et al*., 2006) That results in reduced plaque accumulation which subsequentlyreduces periodontal disease. Nanofiller technology has enabled the production of nanofill composites by bringing together the esthetic features of microfill composites and the mechanical features of hybrid composites.In-vitro studies have shown that these composites had advantageous physical, mechanical and esthetic features. (Mitra *et al*., 2003; Curtis *et al*., 2009; Watanabe *et al*., 2008) However, before nanofill and nanohybrid composites take their anticipated places in routine practice, their successful in-vitro performance should be confirmed by long-term clinical studies.

Dentin adhesives/ Dentin bonding agents

Dental adhesives are the material used to promote adhesion or cohesion between two different substances or between a material and natural tooth structure. Polymerizablesilane 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. 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 seen. (Silikas *et al*., 2007)

Nanoceramics

Nanostructured ceramics may meet the need for translucency of dental restoration. Nanoceramicshave superplasticity and shows good toughness and ductility. The hardness and strength of many nanoceramics are four to five times higher than those of the traditional materials. Most importantly, toughness of nanoceramics ismuch higher than that of traditional ceramics.
Li *et al*. reported the different physical properties of nano-ZrO_2 ceramic materials from the traditional ones. The hardness of traditional ZrO_2 was generally around 1,500, and its fracture toughness was very low, so breakage or crack might easily occur in the processing. However, the hardness of nanozirconia ceramics could reach more than 1,750, increased by about 20%. Not only does its hardness increase, but also the fracture toughness also increased accordingly. (Li *et al*., 2011) Wang *et al*. reported the influence of nano-ZrO_2 content on the mechanical properties and microstructure of nano- ZrO_2 toughened Al_2O_3 and found that the composite had better toughness with 20% nano-ZrO_2, very suitable as dental all-ceramic restoratives. (Wang *et al*., 2006) Glass ceramics based on lithium disilicate with lack of mechanical properties are commonly used in dental veneers and crowns. Due to insufficient mechanical properties of glass ceramics, failure clinical cases have been often reported. To improve mechanical properties of glass ceramics based on lithium disilicate, Persson *et al*. used a sol-gel method to produce glass ceramics in the zirconia-silica system with nanosized grains, which was found to be translucent, with a transmittance of over 70%, and possessed excellent corrosion resistance. It also presented a somewhat lower elastic modulus but higher hardness than the conventional lithium disilicate. (Persson *et al*., 2012)

Acrylic resins

Various nanoparticles such as ZrO_2, TiO_2, andCarbon Nannotubes (CNT) have been used to improve the performance of Polymethyl-methacrylate (PMMA) and the results showed that desired mechanical property enhancement can be achieved in those material with small amounts of nanoparticles. Mohammed and Mudhaffar designed and evaluated the addition of modified ZrO_2 nanomaterials in different percentage (2 wt%, 3 wt% and 5 wt%) to heat-cured acrylic resin PMMA materials. Abrasive wear resistance and tensile and fatigue strength showed highly significant increase with 3wt% and 5wt% of nanofillers, compared to pure PMMA materials. The same results were showed in the study of Hong *et al*. where methacryloxypropyltrimethoxysilane-(MPS-) modified colloidal silica nanoparticles were added to PMMA, which caused a significant increase in tensile strength and tensile modulus. (Hua *et al*., 2013; Mohammed and Mudhaffar, 2012; Hong *et al*., 2003) CNTs and carbon nanofibrils have been used as reinforcements or additives in various materials to improve the properties of the matrix materials. Cooper *et al*. prepared the composites consisting of different quantities of CNTs or carbon nanofibrils in a PMMA matrix using a dry powder mixing method. The results showed that the impact strength of the compositeswas significantly improved by even small amounts of single-wall Nanotubes. (Cooper *et al*., 2002) In recent years, metal oxide nanoparticles (e.g., TiO_2, silver) have been largely investigated for their performances as antimicrobial additives. In particular, TiO_2 is now considered as a low-cost, clean photocatalyst with chemical stability and nontoxicity. Laura *et al*. prepared the PMMA composites, adding TiO_2 and Fe_3O_2 nanoparticles, for simultaneously coloring and/or improving the antimicrobial properties of PMMA. PMMA containing nanoparticles showed a lowered Candida albicanscells adhesion and a lower porosity, compared to standard PMMA.

Yoshida *et al*. showed that a resin composite incorporated with silver-containing nanomaterials had a long-term inhibitory effect against S. mutan. (Yoshida *et al*., 1999) Laura *et al*. formulated PMMA-silver nanocomposites, with fairly good dispersion of silver nanoparticles in the polymermatrix. And the results showed that PMMA-silver nanocomposites significantly reduced adherence of C. albicans and did not affect metabolism or proliferation.They also did not appear to cause genotoxicdamage to cells. These results demonstrated that PMMA-silver nanoparticles might be a kind of suitable candidates to produce nontoxic materials with antimicrobial properties for use in prosthetic dentistry. (Magalh˜aes *et al*., 2012)

Nanocomposite Artificial teeth

Artificial composite teeth containing homogeneously diffused nanofillers have been reported to be superior to conventional acrylic teeth in terms of surface smoothness, abrasion resistance and color stability. Enhanced antifungal activity along with increased fracture toughness is seen in silver nanoparticle modified denture teeth. (Suzuki, 2004; Ghazal *et al*., 2008)

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. (Okita *et al*., 1991) Tissue conditioners could be kept clean by mechanical and chemical methods but this can cause considerable damage to tissue conditioners. (Harrison *et al*., 1989; Nikawa *et al*., 1994) Silver has been well known for its antimicrobial characteristic. 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. (Ki-Young Nam, 2011)

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. (Aziz *et al*., 2003; Hooper *et al*., 2005) 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. 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. (Zhala, 2013) 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. (Han *et al*., 2010)

Implantology

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. (Zarb and Schmitt, 1990) 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. (Briggs *et al*., 2004) Nanoporous alumina has the potential of being rendered by loading the porous structure with appropriate bioactive agents improving cell response and facilitate osseoinductive activity. (Wei *et al*., 1999) 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 and formation of titanium dioxide or titania. (Ducheyne *et al*., 1986; Uchida *et al*., 2003)

Nano Sterlizing Solution

Gens Nano photocatalyst has strong effect on killing almost all kinds of bacteria and virus as including SARS and HSN1. It got silver antibacterial property. Due to photocatalyst it can complete and decompose the bacteria and virus. One more Gandy Enterprises Inc. Florida have introduced a new disinfectant based on superscience of nano-emulsion technology. It uses nano-sized emulsifier droplets of oil (similar in size of HIV virus) that bombard the pathogens e.g. Eco Tru Disinfectant. Advantages of this are: Broad Spectrum, Hypoallergic, Does not stain fabric, environment friendly and compatible with impression material.

Safety Issues

Nanobiomaterial technology is extensively being applied in healthcare services largely because of its various advantages. However, with increased use, concerns about the safety of these nanobiomaterials are being raised. The increased rate of absorption associated with manufactured nanoparticles is the main concern. Nanoparticles have an increased surface area: volume ratio, which leads to increased absorption of these particles through the skin, lungs and digestive tract. Nonbiodegradable nanoparticles when accumulated within the body may be deposited in various organs and may lead to an unwanted reaction within biological tissues. A study conducted by the Swedish Karolinska Institute revealed that iron-oxide nanoparticles were nontoxic on human lung epithelial cells and caused no DNA damage. Zinc-oxide nanoparticles were slightly worse. Titanium dioxide caused only DNA damage; carbon nanotubes caused DNA damage at low levels. Copper oxide was found to be highly toxic and was categorized as a health risk. (Karlsson *et al*., 2008)

Conclusion

In this article, the latest research progress on the applications ofnanomaterialsin prosthodontics was reviewed, which clearly shows that materials used in prosthodontics can be significantly improved after their scales were reduced from micron-size into nanosize by nanotechnology and that the performances of composites can also be enhanced by adding appropriate nanomaterials. This review article could provide some valuable information for the future scientific and technological innovations in the related field. Future development of prosthodontics technology has been recognized to be dependent on the progress of materials science. Nanomaterials have been playing a significant role in basic scientific innovation and clinical technological changes of prosthodontics.

Conflicts of interest: None

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