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Nanocomposites Used In Prosthodontics And Implantology - A Review

Review Article

Revathi Duraisamy[1*], Dhanraj M. Ganapathy[2], Rajesh kumar Shanmugam[3]

[1] Senior Lecturer, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, 162, Poonamallee High Road, Velappanchavadi, Chennai.
[2] Professor and Head, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, Poonamallee High Road, Velappanchavadi, Chennai.
[3] Associate Professor, Nanobiomedicne Lab, Department of Pharmacology, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, Poonamallee High Road, Velappanchavadi, Chennai.

Abstract

Nanotechnology is the science that involves controlled manipulation of particles at the nanoscale dimensions, which allows for development of biomaterials with superior properties and functionality. A wide range of nanoparticles are combined with polymers to form nanocomposites. Such biomaterials have been widely used in various industries especially in the medical and dental field. In prosthodontics, the branch of dentistry that deals with prosthetic rehabilitation of missing teeth, nanocomposites have been incorporated into almost all the biomaterials with the notion of enhancing their properties. In this review, we focus on the application of nanocomposites in prosthodontics and dental implantology.

Keywords: Nanocomposites; Dentistry; Prosthodontics; Nanotechnology; Oral Implants.

Abbreviatons: NM - Nanometer; FPD - Fixed Partial Denture; KN/mm2 – Kilo Newton/Micrometer; PMMA - Polymethylmethacrylate; POSS - Polyhedral Oligomeric Silsesquioxanes; ZrO2 – Zirconium; TiO2 - Titanium diOxide; Ag – Silver; HA - Hydroxyapatite; Col – Collagen; GO – Graphene Oxide; ND – Nanodiamond; ALP - Alkaline Phosphatase; TGF-β - Transforming Growth Factor - Beta.

Introduction

Nanotechnology has become an area of active research in various sectors due to the profound impact they have had on material substances. At the nanoscale, it entails planned and regulated intervention, precision positioning, measurement, and modelling. One nanometer (nm) is a unit of length that equals 1 billionth of a meter ($1 \text{ nm} = 10{-}9 \text{ m}$) to develop biomaterials with superior properties compared to their bulk counterpart. Considering that the size of a usable nanostructure is 1 to 100 nm [1] Customizing and manufacturing the particulate size at the nanoscale level allows control over the fundamental molecular structure, which in turn controls the macroscopic chemical and physical properties.

For medical applications, the nanoparticles interact with cells and tissues at a molecular and subcellular level with a high level of functional specificity, permitting a level of integration among technology and biological systems not previously possible. Nanotechnology has been applied in the biomedical field as a result of extensive research and development. It offers a wide range of advancements and improvements in the prevention, diagnosis, and management of oral ailments in dentistry. Like other branches of dentistry, prosthodontics and implant dentistry have made remarkable progress incorporating dental biomaterials with nanotechnology. The clinical success of materials used in prosthodontics relies on physical properties namely; surface tension, polymerization shrinkage in terms of acrylic, wear resistance, elasticity. They were found to be improved after incorporation of nanomaterials, along with enhanced osseointegration properties for dental implantology. In this review, we discuss the latest advancement made in nanotechnology pertaining to the field of prosthodontics and dental implantology.

***Corresponding Author**:
Revathi Duraisamy,
Senior Lecturer, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, 162, Poonamallee High Road, Velappanchavadi, Chennai - 600077.
E-mail: revathid.sdc@saveetha.com

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Nanotechnology

The word nano originates from the Greek word "dwarf". The concept of nanotechnology was first put forth in 1959 by Richard Feynman. Taniguchi coined the term ‘nanotechnology’ in 1974. The European Union defines nanomaterial as “a manufactured or natural material that possesses unbound, aggregated or agglomerated particles where external dimensions are between 1–100 nm size ranges”. The nanoparticles are characterized by the increased surface area compared to the bulk material and their quantum effects [2].

Figure 1. Surface Area Comparison between bulk material and Nano-Scale Particles [Image Courtesy of Ali and Imtiaz et al. Performance of Conventional Drilling Fluids and Nano Based Drilling Fluids, published in Journal of Applied and Emerging Sciences, 2007;7(1):12-21. ISSN 2415-2633. Available at:<https://journal.buitms.edu.pk/j/index.php/bj/article/view/211>. Date accessed: 04 Sep. 2021.]

Classification of Nanocomposites

Nanocomposites are materials that are produced by hybridization of polymers with inorganic solid particles at a nanometric level. The resulting product is often heterogeneous in nature. This synergistic combination enables nanocomposites to be used in various industries, medical and dental fields. Inorganic nanocomposites are made up of non-polymer-based nanocomposites. Metal-based nanocomposites, carbon-based nanocomposites fullerenes (C60), carbon nanotubes (CNTs), carbon nanofibers, carbon black and graphene, ceramic-based nanocomposites, and ceramic-ceramic-based nanocomposites are the different types. [3].

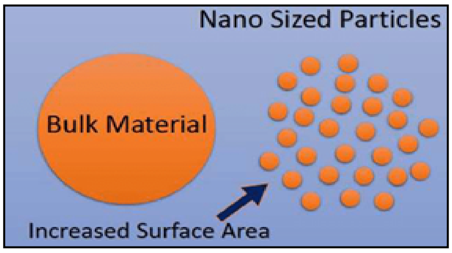
Production of Nanocomposites

Nanocomposites are produced via two key techniques; the bottom-up technique where they are produced at an atomic level or molecular level right from the start through mechanical attrition via grinding large coarse-grained materials. In the top-down technique, the material is ground down to a point where it leaves behind a layer of the nanoparticles usually through sol gel processing. The resulting nanoparticles have various morphologies such as nanopores, nanotubes, quantum dots, nanoshells, nanospheres, nanowires, nanocapsules, dendrimers, nanorods, liposomes [4].

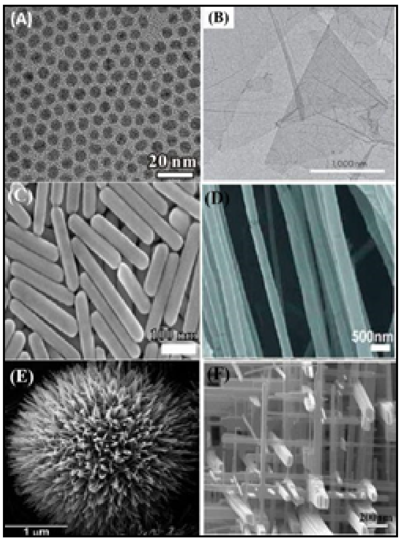
Biomedical Applications of Nanocomposites

The term Nanodentistry was introduced by R.A. Freitas Jr. who first hypothesized the conceptualization of various nanotechnology based techniques in dentistry. Research and Developments in this field has led to many dental treatment procedures fast, reliable, safe & less painful. Some of the areas which use nanodentistry include toothpaste containing nanosized calcium carbonate enabling remineralization of early enamel lesions, tooth sealants & fillers, Antimicrobial nanoparticles in restorative materials, inducing anesthesia, digital imaging, composite filling materials, treatment of hypersensitivity, denture base and implant biomaterials, impression materials, nanosurgical instruments, bone substitutes,

Figure 1. Surface Area Comparison between bulk material and Nano-Scale Particles.



[Figure 2: Nanomaterials with different morphologies: (A) nonporous Pd NPs (0D) [5], (B) Graphene nanosheets (2D) [6], (C) Ag nanorods (1D) [7], (D) polyethylene oxide nanofibers (1D) [8], (E) urchin-like ZnO nanowires (3D)[9], (F) WO3 nanowire network (3D) [10] [Image Courtesy of Jeevanandam, J, Barhoum A, Chan YS, Dufresne A, Danquah MK, Beilstein J. Nanotechnol. 2018, 9, 1050–1074. doi:10.3762/bjnano.9.98]



sterilization products, tissue engineering, Nanoparticle-based drug delivery system for oral cancer treatment and Gene therapy.

Nanotechnology in Prosthodontics

Prosthodontics, which involves the prosthetic rehabilitation of the missing tooth, employs heavy usage of biomaterials such as metals, acrylic resins, ceramics, and polymers, adhesives for the fabrication of dentures, Fixed Partial Denture (FPD) units, maxillofacial prosthesis and dental implants. Since these materials are constantly exposed to harsh conditions for a prolonged period of time in the oral environment such as food mastication, saliva contact, and various issues are expected to arise such as wearing of the dentures, change of colour, excessive polymerization shrinkage and stress related fracture. Incorporation of nanocomposites could significantly improve their physical properties such as modulus of elasticity, polymerization shrinkage, surface hardness, filler loading and long term stability in implants. Nanocomposites were first introduced into dentistry by Filtek Supreme in 2002.

Impression Materials

In order to make impression materials more tear and distortion resistant, Nanofillers are integrated into vinyl polysiloxane, producing a unique siloxane impression material. Such modifications render the impressions materials with high tear resistance, better flow, improved hydrophilic properties and enhanced precision detail. A commercially available nanofilled impression material is the Nanotech Elite H-D.

Another unique discovery of nanocomposites particles is the Polymer nanocomposites or Polyhedral oligomeric silsesquioxanes (POSS), they contain an additional hydrogen atom or an organic functional group, e.g., alkyl, alkylene, acrylate, hydroxyl or epoxide unit. POSS can be chemically linked to polymers and thereby integrated into a polymer matrix, affecting morphological and functional characteristics. Some of the POSS derivatives include POSS-Poly (Ethylene Oxide)-Containing Polymer/Block Copolymer Nanocomposites, POSS-Polyoxymethylene (POM) Nanocomposites, POSS-Polyamide Nanocomposites and POSS-Polypropylene Nanocomposites. They could be used as additions to conventional plastics or as an alternative for them [11]. POSS is currently used in dental adhesives, where a high-strength resin creates a strong bond between both the tooth structure and the restorative material. Traditional polymers as well as impression materials are substantially more susceptible to radiation degradation and erosion than POSS compounds [12].

Nanoceramics

Nanocomposite based ceramic materials, on an atomic level, contain one phase of the material in the nanoscale dimension. The nanoscale reinforcement imparts the ceramic material with high mechanical and thermodynamic properties which significantly increases the hardness and ductility. For example, the knop hardness value of conventional ceramic is around 2000KN/mm2, while nanocomposite reinforced ceramic possess a hardness value of more than 13,000 KN/mm2.

Conventional ceramics suffer from hydrothermal aging 13 When exposed to oral fluids for a prolonged duration, the mechanical stress causes irreversible premature failure of zirconia components 14 Nanoparticles reinforced fully dense zirconia-based ceramics have been shown to be resistant to hydrothermal aging due to their grain size of <100 or <200 nm. As of this day, there are two commercially available Nanostructured Zirconia-Based Ceramics; ZrHP-nano® (ProtMat Materiais Avançados®-Brazil) and NANOZR® (Panasonic Healthcare–The Netherlands).

Nanocomposite Denture Teeth

The demure teeth plays a significant part of prosthodontics as it restores the form, function and esthetics of a completely edentulous patient. They are usually made of porcelain and acrylic. They have drawbacks such as brittle, lack bonding ability to the denture base, and are not easy to polish in terms of porcelain teeth; whereas acrylic teeth are limited by wear. The teeth wear is influenced by a plethora of factors such as chewing pattern, dietary and parafunctional habits, as well the anatomy of the underlying residual ridges.Polymethylmethacrylate (PMMA) and uniformly dispersed nanofillers make up nanocomposite denture teeth. The MF-H (microfilled hybrid) composite used in the three layered Veracia SA teeth is strengthened using layered glass. Nanocomposite denture teeth usually exhibit high lustre with excellent polishing ability and stain-resistance and enhanced wear resistance and surface hardness.

Tissue Conditioners

Tissue conditioners are used in treating irritated oral mucosal tissues due to ill-fitting dentures. However, over the course of time, the conditioners deteriorate with time and are susceptible to colonization by microorganisms. Incorporating inorganic silver nanoparticles increased the broad-spectrum antibiotic efficacy [15]. A systematic review by MS Sheik *et al.*, in 2021 evaluated the literature published regarding the addition of antifungal agents in tissue conditioners had a beneficial effect in preventing denture stomatitis or atrophic chronic candidiasis in long term denture wearers and observed favourable results [16].

Resin Based Materials

Resins are often used in prosthodontics for fabrication of denture materials, and maybe activated through cold cured, heated cured and light cured. Polymethyl methacrylate (PMMA) has ideal physical, chemical and mechanical characteristics for denture base fabrication. Albeit they are limited by dissolution, colour instability, high wear resistance, and leaching of the uncured monomer particles resulting in mucosal irritation [17]. In order to overcome such limitations, various nanoparticles such as Zirconium (ZrO2), Titanium di oxide (TiO2), and carbon nanotubes have been used. The results demonstrated that addition of nanoparticles augmented the physical properties of denture base acrylic resins [18].

The two kinds of resin composites characterised by filler-particle diameters of less than 100 nm are referred to as "nanocomposite". Nanomers as well as nanoclusters are two kinds of non-agglomerated monodispersed distinct nanoparticles that are uniformly dispersed in resins for coatings to make nano composites. To increase particle flow in composites, nanomaterials such as titanium dioxide, aluminium oxide, and silica oxide are added in tiny concentrations (1–5 %). [19]. Metals, plastics, polymers, and composite materials benefit from nano-structural aluminium oxide fibres, which enhance strength and enhance performance. Nano porous silica loaded composite is a relatively novel material that has been shown to improve wear resistance in subsequent applications. Reformulations of interfacial silanes are becoming more focused in tandem with the development of nanoparticles in dental composites. The compatibility of organo silanes like allyltriethoxysilane with nanoparticle fillers like TiO_2 has been proven.

Nanocomposites in Dental Implants

Titanium remains the materials of choice in dental implantology owing to its superior biocompatibility, physical and chemical properties. However they are limited by corrosion, bacterial attacks and high sensitivity, corrosion, bacterial infections, and unresponsive cellular interactions. Therefore, modifying titanium at the nanoscale level to improve its function is a tantalizing option for clinicians and researchers. Osseointegration plays a pivotal role in determining the longevity, stability and clinical performance of dental implants. Osseointegration relies on the type of Implant materials, chemical composition, geometry, biological fixation (bone to metal contact) and surface topography [33].

Cellular events of osseointegration include osteoblastic cell differentiation, proliferation, and protein synthesis have been attributed to the surface roughness of implant material [34]. Implant surface roughness is categorized into macro roughness and microroughness. The microroughness is created through macroporosity by the threaded screw flutes. While macro roughness contributes to

Table 1.

MATERIAL IN USE	AUTHOR	NANOCOMPOSITE USED	EFFECTS	REFERENCE NO
DENTAL CERAMICS	Philipp et al in 2010	Ceramic reinforced Titanium/Zircon nanocomposite (NANOZR) as framework material	No failure, chipping, fracture of the veneering ceramic was observed	[20]
	Tanaka et al in 2015	Clinical performance of veneered NANOZR Ce-TZP/A-nanocomposite (three year follow-up) frameworks for fixed dental prostheses.	Ce-TZP/A-nanocomposite prostheses exhibited a survival rate of 95.5%.	[21]
DENTAL IMPRESSION MATERIAL	Gad MM et al in 2018	Nanocoated ZrO_2 to increase translucency and tensile strength of the polymethyl methacrylate (PMMA) denture base material.	The increase in the tensile strength was directly proportional to the nano-ZrO_2 concentration. The translucency of the PMMA was reduced as the nano-ZrO_2 increased.	[22]
	Oyar P et al 2018	the effect of (0.05% and 0.2%) gold nanoparticle on the flexural strength of PMMA	Significant increase in flexural strength, although not significantly	[23]
	Omidkhoda M et al in 2019	500 and 1000 ppm nanosilver solution mixed with alginate.	*E. coli* colonization was significantly lowered with no change is the chemical setting of the materials.	[24]
	Munikamaiah RL et al 2018	Different concentrations of silver colloidal nanoparticles subjected to two different curing cycles.	mean flexural strength value of 0.5% silver colloidal nanoparticles in denture base resin was above the value of the control group in both curing cycles, 5% concentration, was not favourable	[25]
	Li et al 2011	nano-ZrO_2 ceramic material to test fracture toughness	The hardness of nanozirconia ceramics increased more than 20%, along with	[26]
	Cooper et al in 2002	Carbon nanofibrils in a PMMA matrix using a dry powder mixing method	Improved shear punch strength of the composite materials.	[18]
	Suganya S et al in 2014	Heat cure denture base resins reinforced with Ag° in the ratio of 4:1, 3:1, 2:1	Antimicrobial effect of silver could be used vividly in the denture base for immunocompromised and geriatric patients.	[27]
NANOCURED DENTURE TEETH	Suzuki S et al 2004	Nano-filled denture teeth (Veracia)compared with and micro-filled, cross-linked and acrylic composites	The nano-composite tooth was harder and more wear resistant than the acrylic teeth but not significantly different from most of the cross-linked and micro-filled composite teeth tested.	[28]
	Ilangkumaran R et al 2014	compared the amount of wear between nanocomposite teeth and acrylic teeth	The nanocomposite teeth had less amount of wear than the four layered acrylic teeth	[29]
TISSUE CONDITIONERS	Mousavi SA et al 2009	10% ZnO-Ag nanoparticles	ZnO-Ag nanoparticles inhibited bacterial proliferation	[30]
	Ki-Young Nam in 2011	0.1 - 3.0% silver nanoparticles incorporated into tissue conditioner	Minimal bactericidal effect against *S. aureus* and *S.mutans* strains, a 0.5% for fungal strain	[31]
	Homsiang W et al 2021	15 wt% zinc oxide nanoparticles with 15 wt% nystatin.	The 15% Zn provides antifungal effect up to 14 days without adverse effects on penetration depth and tensile bond strength.	[32]

enhanced mechanical interlocking between the bone and implant surface. Roughness created on the implant surface through surface functionalization influences the adsorption of proteins, osteoblastic attachment [35].

The alveolar bone is composed of crystals of Hydroxyapatite (HA) and collagen fibers. Therefore, functionalization of implant surfaces through nanocomposites results in improved gingival health post implant placement and enhanced stability. The nanocomposite coating on implant offers nano spaced altered implant topography, improved cell-matrix adhesion and increased bone to metal contact thereby, improving the osteoconductive and osteoinductive properties.

Hydroxyapatite Nanocomposite Coating

Hydroxyapatite, a calcium apatite crystal and is an integral part of teeth and bones. Alveolar bone has about 65 percent hydroxyapatite, with physical dimensions of 60 nm x 5–20 nm [36], enamel contains 96 percent inorganic matrix and organic materials, and 4 percent water, and the dentin stratum contains 70 percent inorganic matrix, 20 percent organic matrix, and 10 percent water. In enamel, the normal size of hydroxyapatite crystal lattice is 48 to 78 nm [37]. The hexagonal HA crystallites in enamel are connected to create 4 m diameter rods, but the crystallites in matured dentine are flattened sheets. Upregulation of osseointegration signaling pathway are required for the differentiation of mesenchymal stem cells into osteoblasts. Hydroxyapatite coating on its own exhibits low bond strength with the implant surface and is extremely brittles and fragile, However by combining with other microparticles such microparticles include silica, titanium, collagen, zircon, carbon nanotubes and chitosan, they have successfully sustained on the implant for a longer duration with a higher adhesive strength as they embed to the implant surface [38].

Kim *et al.,* in 2005 observed the properties of HA/TiO2 nanocomposite coating after its application on titanium substrate. They found dense, homogeneous layers of the nanocoating. They observed an increase in the bond strength of the coating underneath the Ti substrate. There was a robust growth of osteoblasts which was confirmed by high levels of alkaline phosphatase (ALP) thereby promoting more bone to metal contact [39].

Teng *et al.,* in 2008 tested the osteogenic potential of 10, 20, and 30 wt. % HA/collagen coating in a thickness of 7.5 mm and observed increased proliferation of cells on implant surface, characterized by high levels of alkaline phosphatase in comparison to pure Titanium substrate or collagen coating which a lower proliferation of cells compared to corresponding HA/collagen nanocomposite [40].

An amalgamation of HA and collagen coating resembles the normal physiology of bone architecture. De Jonge et al in 2010 examined the in-vitro efficacy of collagen/HA coatings. It was concluded that the coating improved the osteoblastic differentiation and mineral deposition [41].

Bioactive glasses include amorphous silica-based materials known to possess excellent biocompatibility, bioactivity, and osteoconductivity. They were introduced by Hench and colleagues for orthopedic implantation devices, and commercially available as 45S5 Bioglass [42]. Not only do they initiate osteoblast proliferation but after degradation the ions, they upregulate the synthesis of protein and induction of growth factor II mRNA expression such as RUNX2, osteoprotegrin-1.

Dimitrievska S *et al.,* in 2011 studied the capacity of the osteoinductive properties derived from mesenchymal stem cells on plasma-sprayed TiO2-based bone-implant coatings with 10% wt hydroxyapatite. They assessed proliferation, cytoskeleton organization, cellular morphology, adhesion and growth. The stem cells demonstrated a high rate of proliferation and differentiation on the implant surfaces coated with HA-titanium surfaces. Furthermore, they also found higher bond strength of the hydroxyapatite-titanium coating compared to implant surfaces coated with hydroxyapatite alone [43].

Mehdikhani-Nahrkhalaji *et al.,* in 2012 evaluated the coating of HA/ bioactive glasses. The coating presented an appropriate topographical surface for cellular adhesion. They concluded that the HA/bioactive glass coating promotes proliferation and differentiation of osteoblasts [44].

Bryington MS *et al.,* evaluated the healing time periods of twenty threaded titanium alloy (Ti6Al4V, Grade 5) implants inserted bilaterally into eighteen rabbit femurs, half of which were prepared to bestow stable hydroxyapatite nanoparticles onto a sandblasted as well as acid etched surface and the other half with a non-coated control surface with only thermal treatment. They came to the conclusion that a variety of factors, including morphology and chemistry, may have impacted the results[45].

Uezono *et al.,* in 2013 investigated the bone formation around titanium rod specimens with a machined surface, hydroxyapatite coating, and hydroxyapatite/collagen (HA/Col) nanocomposite coating in rat calvarium. It was observed that all the HA/Col implants were surrounded by new bone formation. The bond strength also appeared to be increased and the authors inferred that HA/Col-coated implants promoted rapid osseointegration. [46].

Nanocomposites derived from silicate of zirconium are known to leach silicate ions which has been hypothesized to induce bone formation through the differentiation of osteoprogenitor cells. Karamian *et al.,* in 2014 found the addition of zircon/HA coating increased the roughness of HA coating, which would act as a scaffold for the developing coagulum thereby facilitating rapid wound healing and greater osseointegration [47].

Besinis A *et al.,* in 2017 evaluated the antimicrobial efficacy of implant substrates coated with silver nanocomposites and hydroxyapatite. Silver-HA nanocoating limited bacterial proliferation in the surrounding media, and there was reduction in the biofilm formation. It was concluded that application of a dual layered silver-HA nanocoating imparts antibacterial and antiplaque formation properties to titanium implants [48].

Carbon Nanocomposite Coatings

Carbon nanomaterials like graphene, fullerene, titanium dioxide, hydroxide apatite, chitosan, collagen, and zirconia have shown to induce cellular activities such as proliferation, adhesion, migration, and differentiation into osteoprogenitors cells [49]. The coatings of implant surfaces are achieved through physicochemical coating techniques, such as plasma spray, physical adsorption, dip coating, spin coating, electrophoretic deposition, electrochemical deposition, chemical vapor deposition, and several other modern techniques.

Facca S *et al.,* in 2011 studied carbon nanotube (CNT)/HA coating on titanium implants embedded in murine calvaria. Normal growth of bone was seen around the implants with no relative cytotoxic effects that could be induced by the carbon particles. The authors concluded that CNT coating with HA induces higher osseointegration as compared to HA [50].

Metzler *et al.,* in 2013 prepared nanodiamond coated titanium alloy implants in pigs and assessed the amount of bone formation through histomorphometric study. Results demonstrated that newly generated bone integration made intimate contact with the ND-coated surfaces between the implant channels of the mature bone. Following two and five months of insertion, ND-coated TiAl6V4 showed improved bone-to-implant contact as compared to bare TiAl6V4. In addition, the ND layer demonstrated a tight contact between the implant and freshly created bone, with no delamination or particle dissociation, demonstrating the benefits of this coating approach [51].

Zeng Y *et al.,* in 2016 modified the implant surface using graphene oxide and HA (GO/HA) composite coating.After GO was added to the composite coating, it showed improved crystallinity and a bonding strength of 25.4 1.4 MPa. Furthermore, GO and HA aided MG63 cell proliferation and the early stages of osteogenesis, indicating that using an ECD-coated GO/HA layer to make Ti implant coatings for clinical use is a potential technique [52].

Shi YY *et al.,* in 2016 fabricated a nanocomposite coating composed of graphene oxide-chitosan-hydroxyapatite (GO-CS-HA) composite coating on Ti substrate through electrophoretic deposition. The results showed that there was a uniform distribution of the nanocoating on the implant substrate due to the HA crystals. This could effectively shield the implant from corrosion and drastically reduce the chance of bacterial attacks by S.Auerus [53].

Apart from HA coating, Graphene oxide nanocomposites with titanium increased surface roughness and wettability on the implant surface. Further in-vivo assays performed on weistar rats revealed that there was an increase in new bone formation, the osteoblasts were confirmed through Alkaline Phosphatase assays, implying that Graphene nanocomposite was capable of inducing stable osseointegration of Ti implant [54].

Wang *et al.,* in 2019 studied the osteogenic potential of a titanium implant alloy coated with graphene oxide coating (Ti–G–GO). Mesenchymal cells raised on the Ti–G–GO group significant cell proliferation and differentiation. Histomorphometric tests revealed a higher rate of osseointegration in the Ti–G–GO. The authors stated that this could be due to the improved surface hydrophilicity caused by the graphene oxide coating and formation of HA crystals and concluded that the combined use of the surface texture of the implant and the nanocoating would be a potential option to improve osseointegration surrounding dental and orthopedic implant [49].

The osteoinductive potential of graphene oxide coated implant substrate was investigated by Li Q *et al.,* in 2020 by in-vivo experiments on rat models. The coated implants demonstrated surface wettability and protein adsorption capacity. Proliferation and osteogenic differentiation were both significantly higher in bone mesenchymal stem cells in vitro accompanied by upregulation of vinculin and the FAK/P38 signaling pathway. The authors also observed enhanced bone regeneration when the implants were introduced in rat femurs which showed accelerated osteogenesis [55].

Chitosan Nano Coating

Chitosan, a naturally extracted polysaccharide from crustacean shells through deacetylation of chitin has excellent biocompatibility, biodegradability and antimicrobial properties. Meharali et al in 2016 experimented with a nanocomposite material based on the combination of graphene and chitosan and hypothesized to enhance the physical and biological profile of implant material. It was found that 1 wt % GO/Chitosan coating improved bond strength of the coating by 70%, hardness by 150%, and elastic modulus by 240%. They also exhibited hydroxyl apatite crystals generating capacity. The authors inferred that Graphene oxide/chitosan coating could be a promising implant coating material [56].

Park *et al.,* in 2017 tested the anti-corrosive properties of HA/Chitosan coating on titanium alloy implant surfaces. Improved resistance to corrosive chemical reactions was exhibited by HA/CS coated implant compared to the controls that had hydroxyapatite coating only [57]. The fundamental biological and antimicrobial properties of the HA/CS coating was investigated by Li et al in 2019 in a cell culture experiment which analyzed the biological properties, inhibition zone, and bacterial count. There was a significant zone of bacterial inhibition of species such as E.coli along with augmentation of the HA layer which facilitated cell spreading, proliferation and adhesion [58].

Wang X *et al.,* in 2021 fabricated a hydroxyapatite coated titanium implant with outstanding mechanical and biological qualities and placed them in beagle dogs and assessed the cytotoxicity, alkaline phosphatase (ALP) and transforming growth factor (TGF-β1) expressions.The levels of ALP and TGF-1 were marginally elevated. The transcript levels of ALP and TGF-βRI were higher in the test group compared to the controls at 7 days. The authors concluded that hydroxyapatite coated titanium implants showed signs of osteoneogenesis of dental implants in vivo and vitro [59].

Current Limitations

Although, the nanocomposites demonstrate excellent and promising results. There are certain limiting factors such as the fabrication of nanocomposite coating proves to be meticulous and expensive. The lack of data regarding the biodegradability and toxicity profile on the carbon nanoparticles remains to be elucidated [60]. Hydroxyapatite coating are known to harbor bacterial colonization since the roughened surfaces acts as a plaque retentive hotspots leading to peri-implantitis. It was also published in a report that 65% of the 50-μm-thickness HA coating was completely resorbed after 16 weeks leading to mobility of the implant. [61]. The uniform coating of the nanocomposite on the implant surface proves to be troublesome as these nanoparticles tend to agglomerate quite often. There is a lack of guidelines and rules governing the use of nanoparticles in dentistry. Future in-vivo studies in human subjects are necessary in order to extrapolate the results into clinical practice thereby prolonging the clinical performance, stability and longevity of dental implants.

Conclusion

Transition of microparticle to nanoparticle would create a paradigm shift in materials used in prosthodontics and implantology. The physical, mechanical and biological properties of materials can be significantly enhanced along with imparting osteoinductive properties to the implant materials by adding appropriate nanomaterials.

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