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Review Article

Nanotechnology in prosthodontics – Small particles big impact

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ABSTRACT

Nearly every aspect of research and development has been significantly impacted by nanotechnology. Notably, nanotechnology is also having an impact on the fields of health and dentistry by utilising its enormous potential. When compared to bulk material, nanoparticles have proven to be far more powerful. Because of its unusual size, it is much easier to change and improve a variety of features, including surface chemistry, charge, bonding ability, and different biological properties. Richard P. Feynman, a late Nobel Prize-winning physicist, developed the idea in 1959. The area was researched in the years that followed for the creation of nanoscale devices and nanosized particles to produce improved qualities. Regularly used dental materials with limitations of inferior physical and biologic qualities can be changed with nanoparticles to improve the material's inherent properties while staying within budgetary constraints. Unique qualities of a nanoscale material may not only have a significant impact on its biological properties, such as cytotoxicity and biocompatibility, but also on its physical properties, such as tensile strength, fracture resistance, and surface hydrophobicity.

1. Introduction

Richard Feynman coined the word "nanotechnology" in 1959 to describe the scientific method of developing useful materials, gadgets, and systems by manipulating atoms on a nanoscale scale and taking use of novel phenomena and qualities at that length scale.[1] The word "Nano" is a Greek word that means "dwarf". One nanometer is one billionth of a metre, or 10^{-9} of a metre, to put it another way. Because their size is smaller than the crucial lengths defining many physical events, nanotechnology has a lot of promise. The use of nanotechnology in medicine would make it possible to tailor each patient's diagnoses and treatment regimens depending on their genetic makeup.[2]

Nanotechnology involves manipulation of individual atoms, developing nanoscopic machine assemblers and creating enough assemblers from nanomachines called replicators.[2] Despite nanotechnology being a far-fetched idea with no near-term applications, nanoparticles, nanopores[1] and nanotubes[2] already play a significant role in industry, environmental remediation, medicine, science and even in the household.

Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale, enabling unique applications.

2. Discussion

Late Nobel Laureate Richard P. Feynman first presented the concept of nanotechnology in 1959. He added, "There is plenty of room at the bottom," recommended employing machine tools to produce smaller machine tools, these are to be used in turn to make still smaller machine tools, and so on all the way down to the atomic level, noting that

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this is "a development which I think cannot be avoided". In the well-known lecture given in 2000 by the late scientist Richard P. Feynman, Freitas reiterated the forecast made in 1959. (who won the Nobel prize for physics in 1965). This forecast came along with the definition and vision of nanotechnology, which held that the atomic-level accuracy provided by molecular devices functioning at the nanoscale was an unavoidable technological development.[3]

Nanotechnology is typically defined as the study and development of materials, technologies, and systems that display physical, chemical, and biological properties that differ from those seen on a larger scale. Nano is derived from the Greek word meaning dwarf (matter smaller than scale of things like molecules and viruses).[4]

Engineering functional systems at the molecular level is known as nanotechnology.

The term "nanotechnology" originally referred to the anticipated capacity to build things from the ground up utilising currently being developed tools and processes to create full, high performance products.[5]

2.1. One major way that nanotechnology is expected to transform health care

1. Through the development of new techniques for disease detection and prevention.
2. Choosing a course of treatment based on the patient's profile.
3. Gene therapy and drug delivery.[6]

Generally speaking, nanotechnologies are made up of three successively more potent and overlapping molecular technologies:

1. Nanoscale-structured materials and apparatuses for targeted drug delivery, smart pharmaceuticals, and enhanced diagnostics and biosensors.[3]
2. Molecular machine systems and medical nanorobots enable for fast pathogen diagnosis and extermination, as well as effective augmentation and improvement of normal physiological function.[7]

3. Nanodentistry

By the use of nanomaterials, biotechnology, including tissue engineering, and nanorobotics, nanodentistry will make it feasible to maintain almost perfect oral health. Trends in oral health and illness may shift the emphasis away from a particular diagnosis or treatment approach.[6]

Both "top down" and "bottom up" procedures can be used to create a wide variety of nanoscale structures.

3.1. Top down approach

The top-down assembly techniques used to create nanoscale structures are mostly expansions of those currently utilised in micron-scale small-scale assembly. The nanodimension is reached through further downsizing. The methods utilised to create nanoscale structures are called bottom-up fabrication techniques.

3.2. Nano dentistry as top down approach

1. Nanocomposites
2. Nano Light-Curing Glass Ionomer Restorative Materials
3. Nano Impression Materials
4. Nano-Composite Denture Teeth
5. Nano solutions
6. Nanoencapsulation
7. Plasma Laser application
8. Prosthetic Implants
9. Nanoneedles
10. Bone replacement materials

Bottom – up approach: To combine smaller atoms into more intricate structures.[8]

3.3. Nanodentistry as bottom up approach:[9]

1. Nanocomposites
2. Nano Light-Curing Glass Ionomer Restorative
3. Nano Impression Materials
4. Nano-Composite Denture Teeth
5. Nano solutions
6. Nanoencapsulation
7. Plasma Laser application
8. Prosthetic Implants
9. Nanoneedles
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3.4. Concept of nanomaterials

1. The changes in physical properties of nanoscale materials allow for novel uses.[10]
2. The small size effect is the energy threshold at which interactions between nanoparticles (interactions like melting, bonding, boiling, dissolving, etc.) can occur. This effect can be particularly useful in dental materials to increase flexure strength since, in contrast to typical sized particles, they conform to shear strength instead of resisting it.[10]

3.5. Nanomaterials applied in prosthodontics

1. Dental materials nanotechnology research primarily focuses on two things:[11]
2. New inorganic nanoparticles being prepared.
3. Use inorganic nanofillers to modify the surface.
4. Due to their widespread use in ceramics, metals, resins, and composites, there is a lot of room for dental material innovation and improvement. Nanometal

offers greater antibacterial characteristics, according to studies.[11]

3.5.1. Nanoceramics

1. Because to its high biocompatibility, good mechanical qualities, and aesthetically pleasing look that is extremely close to that of natural teeth, ceramic materials have been utilised in dentistry for the creation of dental restorations for a very long time.[12]
2. One of the primary research areas in the field of dental materials is the creation of entirely metal-free alternatives.[12]
3. In the microstructure phase, a ceramic material with nanoscale dimensions is referred to as nanoceramics. Nanoceramics offer outstanding, distinctive qualities that set them apart from traditional ceramics Nanoceramics differ from normal ceramics in that they have special qualities including high toughness and ductility. Nanoceramics possesses greater strength and hardness in terms of mechanical qualities. Many nanoceramics have four to five times the strength and hardness of conventional ceramics. Most notably, nanoceramics are much more durable than conventional ceramics.[12] Due to their outstanding mechanical and electrical capabilities, carbon nanotubes have received a lot of attention as material reinforcement.[11]

Dental veneers and crowns commonly use glass ceramics with no mechanical characteristics based on lithium dioxide.

3.5.2. Nano resin based materials

Since1930, PMMA has been one of the materials most frequently utilised in dentistry for the creation of denture bases. This is mostly because it is aesthetically pleasing, simple to produce, processable, and reparable. Although PMMA has strong dimensional stability, it has weak antibacterial and low fracture resistance. Any kind of prosthesis fracture requires time-consuming, expensive, and most significantly, inconvenience for the patient. Nanotechnology will be used to create PMMA, which will have improved mechanical qualities and be more biocompatible.[13]

3.5.3. Various nanomaterials used in PMMA:

3.5.3.1. Carbon nanotubes and pmma. According to studies, adding carbon nanotubes to PMMA will improve its qualities because they are 10-100 times stronger than steel and weigh a tiny fraction of the amount of steel. Carbon nanotubes are incredibly light while also being robust and tough. According to Saad Bin Qasim and colleagues' study, carbon nanotube-reinforced light cure denture base resin demonstrated superior impact and flexural strength.[13]

In order to avoid complications caused by microbes, Kyoung-Im Kim 22 successfully developed CNT-PMMA that was drug-free and had antimicrobial adhesive characteristics. Blackening of the prosthesis is one of the main issues with CNT-incorporated PMMA, though.[13]

3.5.3.2. Silver nanoparticles and pmma. A.F. Wady et al. assessed the efficacy of a silver nanoparticle solution against candida albicans and the impact of adding silver nanoparticles to an acrylic resin used to make dentures on the hydrophobicity of the material. It was determined that the presence of silver nanoparticles decreased the resin's hydrophobicity, proving that they exhibited antifungal properties.[13]

3.5.4. Nanocomposite

The invention of resin-based composite technology has been one of the major developments in restorative dentistry. Both the anterior and posterior restorations in the realm of cosmetic dentistry have been mostly dominated by them. The application of dental composite in restorative procedures still faces certain difficult challenges, including polymerization shrinkage and low strength.[12]

The inferior mechanical characteristics of low shrinkage dental composites for clinical application is a significant barrier to their development. A number of innovative restorative materials have entered the market as a result of patient desire for superior aesthetic restorations. As opposed to earlier composites, restorative materials are now frequently made with nanocomposites, which have better adhesive, aesthetic, and mechanical qualities. Traditional fillers are substantially different from nanofillers, which calls for a change in production strategy from top-down to bottom-up.[12]

Nanotechnology has made it possible to create nano-dimensional filler particles, which are introduced to composite resins either singly or in nanocluster form. Traditional fillers are not like nanofillers.[14,15]

The newly developed nanomaterial is nanocomposites and nanohybrids.

3.5.4.1. Nanocomposites. Use nanometer- sized particles throughout the resin matrix.

Nanohybrids: Consider merging filler technology with particles having a diameter of a few nanometers.

The inclusion of nanoparticles in composites can have therapeutic and/or preventive effects, such as reducing the buildup of biofilm, preventing demineralization, remineralizing tooth structure, and battling cavity-causing bacteria.[12]

3.5.4.2. TiO_2 reinforced resin based composite. To increase the microhardness and flexural strength of composites, titanium dioxide nanoparticles were treated with organo silane ally triethoxysilane (ATES).[16]

3.5.4.3. Nanocomposites containing alumina nanoparticles. The hardness, strength, and elastic modulus of the nano composites have all increased.[16]

3.5.4.4. Calcium phosphate and calcium fluoride nanoparticles based composites. Composites now contain materials that release calcium phosphate and calcium fluoride, which have been found to remineralize tooth structure. A "smart" substance that has prevented secondary caries has also maintained the level of calcium (Ca) and phosphate (P) ion release through recharging and release. A 20 nm-sized substance called nanohydroxyapatites (HAP) has mimicked the natural components of human enamel and demonstrated anti-caries healing capabilities.[16]

3.5.4.5. Ormocers (Organically Modified Ceramics). These nanoparticles have a polysiloxane backbone that is typically employed in glass and ceramics. The pigments iron oxide, titanium oxide, and aluminium sulfo silicate have been added for printing. The microscopic crack propagation was avoided thanks to these nanoceramic particles. It is offered for sale as Ceram X mono (DENTSPLY).[16]

3.5.5. Dental impression materials with nanofillers in prosthodontics

A negative imprint or a positive digital image of the intraoral anatomy is referred to as a digital impression. This type of impression is used to cast or print a 3D reproduction of the anatomic structure for use as a permanent record or in the creation of a dental restoration or prosthesis.[12]

Impression material refers to any substance or mixture that is used to create a false impression or reproduction. The capacity to replicate details, elastic recovery, and resistance to tensile strength are of the utmost importance to make dental prosthesis without the need for corrections as it is the primary stage in achieving a well-fitting restoration. For precise castings and impressions to be made of the hard and soft tissues of the mouth, the hydrophilicity of the impression materials is absolutely essential. Despite the fact that poly vinyl siloxanes (PVS) are naturally hydrophobic, adding nanofillers, such as silica nanofillers processed in a top-down manner, to PVS results in a material with improved flow, hydrophilic properties, fewer voids in the margins, and better model pouring with more accurate and precise detail placement.[12]

3.5.6. Tissue conditioners with nanoparticles in prosthodontics

Patients who need to restore their missing dentition frequently utilise removable dentures. Denture use over an extended period of time or inadequate denture maintenance, however, can result in opportunistic oral infections, particularly in immunocompromised and handicapped elderly individuals.[12] The most typical inflammatory response of the oral mucosa beneath a denture is stomatitis caused by dentures. It has been suggested that the superficial tissue surface of the denture be ground off, followed by relining with tissue conditioner, in order to eliminate fungal deposit from an acrylic denture foundation. But regrettably, in some circumstances, these tissue conditioners offer a favourable environment for the growth and colonisation of various microorganisms, which may increase the difficulties associated with the use of dentures. The integration of antimicrobial/antifungal compounds into tissue conditioners to inhibit microbial adherence was the topic of numerous in vitro and in vivo research.[12]

3.5.7. Maxillofacial materials with nanoparticles in prosthodontics

Maxillofacial prosthesis have been created using synthetic materials like silicones. They restore and preserve the health of the tissues, replace any tissues lost as a result of injury or disease, and enhance the aesthetics of the affected areas.[16]

The materials that are utilised to make maxillofacial prostheses must have a number of desirable qualities, including good tear strength, tensile strength, hardness, water sorption, colour stability, and biocompatibility.[12]

With the development of nanotechnology, attempts have been made to improve the properties of elastomers by adding nanoparticles to them. Many nanoparticles have been examined for their impact on mechanical properties, including Ti, Zn, Ce, $BaSO_4$, POSS, ceramic powder, and silica. The enhancement of hardness, tear resistance, tensile strength, percentage elongation, and colour stability was achieved by the addition of different nanoparticles at concentrations ranging from 1% to 3%.Nano-CeO_2 concentrations of 1% and 3% increased the colour stability and hardness and tear strength, respectively. Nanoparticles with fungicidal action, such as silver nanoparticles (Ag NPs), can be coated on facial prostheses to act as an antifungal agent. Silicone elastomer's hardness was reduced when silver nanoparticles were added at a 20 ppm concentration, but rip strength and colour stability were unaffected.[12]

3.5.8. Nano technology in implants

In dental surgery, implants are frequently used to restore teeth. Obtaining and maintaining osseointegration as well as the epithelial connection of the gingiva with implants is one of the difficulties in implantology. Direct bone bonding may assure a biomechanical anchoring of the artificial dental root, while an intimate interface between the gingival tissue.

It has been demonstrated that altering surface roughness can improve implant clinical performance and bone-to-implant contact. The most popular techniques for reducing the surface roughness of metal implants included grit blasting, anodization, acid etching, chemical grafting, and ionic implantation.

3.6. Challenges nanotechnology is faced with

1. Precise placement & fabrication of nanoscale parts
2. Low-cost mass production methods for nanorobots.
3. Biocompatibility
4. Poor incorporation of clinical research.
5. Resources and aptitude.

4. Conclusion

Nanomaterials have proven fundamental to the development of basic science and clinical technology in prosthodontics. It demonstrates how the prosthodontic materials' many properties, including modulus of elasticity, surface hardness, polymerization shrinkage, and filler loading, can be significantly improved after their scales were reduced from micron to nano size by nanotechnology. The advancement of material science in prosthodontics is creating new opportunities for extensive and abundant research while keeping in mind the security, effectiveness, and usability of these new technologies. Dental treatments will become more efficient and effective thanks to nanodentistry. Nanotechnology does, however, have a huge potential for abuse and exploitation on a scale and scope that has never been seen before, just like with all other technologies, if it is not properly managed and directed.

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6. Conflict of Interest

None.

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