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Journey of nanoparticles in orthodontics - A review

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Abstract

The science of miniaturization (nanotechnology) is manipulating matter at nanometer level and the application of the same to medicine is called nanomedicine. Nanoparticles have been applied in various fields of dentistry ranging from diagnosis to prevention and treatment. Nanotechnology can be employed in orthodontics to enhance the quality of treatment by improving the material characteristics in terms of both physical and chemical nature. It has a wide range of applications ranging from nanocoatings in archwires and brackets, elastomeric ligatures as local drug delivery, antimicrobial action, atomic force microscopy to some future applications such as shape memory polymers, mandibular growth stimulation with gene therapy, acceleration of orthodontic tooth movement, and use as biomechanical sensors and nanorobotics. The present review aims to provide an insight into the various

nanoparticles available, their need, mechanism of action, usage in dentistry with special emphasis on their application in orthodontics and an overview of their future aspects and toxicity.

Key words: Nanoparticles, Orthodontics, Nanomaterials, Nanotechnology, Nanodentistry

Introduction

The term "nano" conjured up a seismic shift in the field of science and technology and has its origin from the Greek word nannos meaning dwarf[1]. Nanoparticles as defined by British Standards Institution are those particles in which all the fields or diameters are in the nano scale range[2]. According to the European Commission "Nanomaterial is defined as a natural, incidental, or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate of 50% or more of the particles in the number, size distribution, one or more external dimensions is in the size range 1–100 nm[3]. In specific cases and were warranted by concerns for the environment, health, safety, or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1% and 50%"[4].

The science of manipulating matter, measured in the billionths of a nanometer, roughly the size of two or three atoms is referred to as Nanotechnology[5]. Convergence of nanotechnology with dentistry and medicine recently led to an interdisciplinary field, nanodentistry which maintains near-perfect oral health through the use of nanomaterials including tissue engineering and nanorobotics[6]. Nanomaterials are used in many areas of dentistry, such as conservative dentistry, endodontics, oral and maxillofacial surgery, periodontics, orthodontics, and prosthetics[7,8]. Orthodontics is a branch of dentistry dealing with the improvement of occlusal conditions and facial aesthetics in both children and adults. With the advent of technology better opportunities are provided to both patient and orthodontist due to new physiochemical, mechanical, antibacterial properties of nano sized materials.

Historical Perspective

Carbon nanotubes and cementile nano wires found in wootz steel were used by artisans in Mesopotamia to create a glittering effect on pots which was a result of metallic film containing silver and copper and this dates back to 600 BC[9]. The term nanotechnology was coined by Norio Taniguchi at the University of Tokyo, encompassing a multitude of rapidly emerging technologies based upon the scaling down of existing technologies to the next level of precision and miniaturization[10]. In 1959 physicist Feynman introduced the concept of nanotechnology and considered it to be an unavoidable improvement in the advancement of science. He explained the possibility of working with and controlling the atoms and molecules that make up matter, which is essentially the bottom-up approach of nanotechnology[1,11]. Gerd Binnig and Heinrich Rohrer were awarded Nobel Prize for developing scanning tunneling microscope in 1986[12]. Carbon nanotubes were discovered by Sumio Iijima in 1991 and the commercial usage of nanotechnology started in early 2000s with titanium dioxide, zinc oxide, and silver nanoparticles[12].

Need In Dentistry

The gateway to the human biosystem is oral health. Biofilms comprising of bacteria and yeast exist as microbial communities, can lead to dental infections and these infections can be prevented by mechanical removal of biofilms supplemented by antimicrobial agents. But prolonged usage of antibiotics and other antimicrobial agents often lead to antibiotic resistance[13]. Prolonged adherence of biofilm to the hard and soft tissues of the oral cavity damages the structural integrity of these tissues. Of late various restorative materials such as amalgam, composites, glass ionomer cement & ceramic, stainless steel crowns are being used to prevent further damage but they have their own disadvantages in terms of strength, porosity etc. In order to overcome the drawbacks, nanotechnology which describes materials that have mechanical and chemical properties superior to those used on a bulk scale, and have a structural range at the atomic level of 1-100 nm are being used[14,15]. Physical, chemical, electrical, optical properties of compounds are enhanced by the use of nanomaterials because of which nanotechnology became a potent and lethal aid in various medical & dental applications. To name a few, dental remineralization, soft and hard tissue regeneration, local anesthesia, orthodontic drug delivery systems, permanent hypersensitivity cures, and the treatment of periodontal disease and dental caries, dental implant and temporary anchorage devices where nanotechnology is being harnessed for its benefits[16,17].

Mechanism of action

The high surface: volume ratio along with smaller diameter of nano particles not only improves the mechanical properties but also enhances the antimicrobial action by damaging the cellular membrane of micro organisms thereby impairing their action[18]. The most commonly proposed mechanism to explain how nanoparticles render antimicrobial action is contact-mediated biocidal action. Other mechanisms include metal ion release, oxidative stress. In contact- mediated biocidal action, nanoparticles being positively charged adhere to the negatively charged bacterial cell wall, thereby altering its permeability and rupture and leakage of intracellular organelles[19,20,21]. The other added advantages of nanoparticles being used for their antimicrobial action is they are not affected by antibiotic resistance mechanisms and they have targeted antimicrobial activity with minimal adverse effects on the host. Nanoparticles that are currently in use include nanopores, carbon nanotubes, nano-capsules, nanorings, nanospheres, dendrimers, quantum dots, liposomes, fullerenes[22].

Different Nanoparticles

Some of the successfully employed nanoparticles include:

Silver

The bactericidal properties of silver are widely accepted in the field of medicine. Owing to their small size, silver nanoparticles readily penetrate the bacterial cell membrane by targeting the bacterial peptidoglycan leading to structural damage and ultimately cell death. They also prevent the bacterial cell replication by interacting with proteins[23,24].

Gold

Antibacterial and antifungal properties are two major properties exhibited by gold nanoparticles. They are also widely used for delivery of antimicrobial agents. Gold nanoparticles were found to exhibit osteogenic potential by stimulating osteogenic differentiation. They also found their application as contrast agents for imaging \and immunochemical studies for protein identification[25,26].

Copper

Copper oxide being a stable compound exhibited antimicrobial properties similar to silver. Reactive oxygen species (ROS) are generated from copper oxide nanoparticles which adhere to the bacterial cell wall and enhancing the oxidative stress of the cells and this contributes to their antimicrobial activity. They are mostly synthesized in micro emulsion form[27].

Zinc

Zinc nanoparticles exhibit a wide range of properties which include, antibacterial, anti-corrosive, UV filtering, anti fungal, good biocompatibility with less toxicity. Their mechanism of action is through disruption of enzyme systems and inhibition of metabolism of sugars[28].

Zirconia

Zirconia oxide is a metal oxide which is aesthetically white in color. It majorly contributes to the overall strength of restorative materials. Other applications include enhanced surface area and biocompatibility[29].

Chitosan

Most of the nanoparticles which are in use are of metallic in origin because of which safety remains a concern. Local drug delivery carriers are being investigated as a potential platform for the release of bioactive molecules through the introduction of chitosan nanoparticles. Chitin is a natural polymer that is present in the exoskeleton of crustaceans, the deacetylation of which gives chitosan[27,30].

Titanium dioxide

Titanium dioxide nanoparticles upon exposure to visible or UV light produce special photocatalytic property. The formation of hydroxyl radicals by a photocatalytic reaction in the presence of water, in turn damages polyunsaturated phospholipids in the peptidoglycan cell membrane, finally invading the cell and damaging the DNA contributing to the bactericidal activity. The other important properties include white color, low toxicity, high stability and low cost[31].

Hydroxyapatite

The term osteoconductive refers to the ability to support osseous growth when placed near viable bone or cells with osseo differentiation potential. Increased remineralization of dentin and enamel was observed with toothpastes containing hydroxyapatite nanoparticles compared with amine fluoride toothpastes. They can be utilized as gene carriers for effective gene transfection, because of their ability to absorb DNA molecules[32].

Silica and Silicon dioxide

One of the most intriguing features which make Silica and Silicon dioxide nanoparticles beneficial for biomedical applications is their large surface area with bioactive functions which make them a potential filler for restorative dental application[33].

Poly-lactic-co-glycolic acid (PLGA)

The US Food and Drug Administration approved PLGA for biomedical applications because of its biocompatibility and bio-degradability, given that its biodegradation results in water and CO_2. Biocompatibility and biodegradability properties, the antimicrobial properties of PLGA are evident in dental applications. The hydrophobic nature and the cationic surface charge of these particles add on to their antimicrobial activity[34].

Application in the field of orthodontics

Acceleration of tooth movement

Of late, lot of emphasis is being laid down to focus on accelerating methods for tooth movement due to huge demand for a shorter orthodontic treatment time. Procedures like corticotomy, distraction osteogenesis, prostaglandin injections, low-level laser therapy and mechanical vibration and now the focus is on using nanorobots to hasten orthodontic tooth movement is slowly taking shape. Nanorobots directly manipulates the periodontal tissues, allowing rapid and painless tooth straightening, derotation and vertical repositioning within minutes to hours. Optiflex wires impregnated with nanocomposite materials is one of the revolution in the field of orthodontics[35].

Hollow wires

Ultrasonic spray pyrolysis synthesis method is used to produce Nickel-Titanium oxide composite nanoparticles and the wires coated by these particles are called as hollow wires. NiTi nanoparticles are coated via electrospinning on a textile or polymer fiber and then the fiber is removed to produce a hollow wire for orthodontic purposes. This wire could potentially have the shape-memory and super elasticity properties, while possibly reducing the material needed for the wire production[36].

Elastomeric Ligatures

White spot lesion is one of the most commonly encountered events at the bracket tooth interface. The most common method of ligation in the field of orthodontics is through elastomeric ligatures which can serve as local drug delivery of anticariogenic, anti-inflammatory and anti bacterial nanoparticles[37].

Dental Biomimetics

One of the major concern in fixed orthodontic treatment is enamel demineralisation adjacent to brackets and bands. Calcium nanophosphate crystals, which are less than 100nm, organised in crystalline form of hydroxyapatite have been developed recently. Bioactivity was increased as result of increased surface area and wettability, which in turn helps in the release of calcium, phosphate and fluoride ions which are organised as fluorapatite and calcium fluoride on the demineralised surface of tooth[38].

Anti microbial agents

Nanoparticles present a large surface-to-volume ratio, which provides a large surface area for antimicrobial activity by close interaction with microbial membranes. Antimicrobial agents like Silver and Titanium dioxide nanoparticles may be used in composites and glass ionomer cements[39] show highly bactericidal activity. Hydrogels are one of the various kinds of polymeric systems which have gained importance of late, are used as drug containers or release rate controlling barriers[40]. Hydrogels swell but not dissolve when brought in contact with water, so they are commonly used in clinical practice and experimental medicine for a wide range of applications, including biosensors, tissue engineering and regenerative medicine.[41]

Nano adhesives

Nano adhesives are nano solutions with filler-particle sizes of ≤ 100 nm, used for bonding orthodontic appliances. Nano composites are prepared by adding nano sized filler into composites by the process of Flame pyrolysis[42]. Higher dentin and enamel bond strength, high stress absorption, longer shelf life, durable marginal seal, no separate etching required and fluoride release are some of the advantages of using nano adhesives.[44].

Nano Coated archwires

There is friction between the bracket slot and archwire when the tooth slides along the archwire. In order to negate the friction, heavy forces have to be applied which in turn has a deleterious effect on the anchor tooth/teeth and this friction can be minimized by coating the arch wire with nanoparticles. Fullerene like tungsten disulfide nanoparticles on the archwire act as a dry lubricant which reduced the coefficient of friction and also improved the corrosion resistance[45,46].

Nanoindentation

The major advantage of atomic force microscope (AFM) is the production of three dimensional images in the real space with a very high resolution. Many methods such as laser spectroscopy, contact surface profilometry and atomic force microscopy are used to measure the surface characteristics of arch wires. A nanoindenter coupled with AFM is used to evaluate nano-scale surface characteristics of biomaterials[47,49].

Future Applications

Nanolipus Devices

LIPUS stands for low intensity pulsed ultrasound. Through these devices ultrasound which is a form of mechanical energy is transferred as acoustic waves through and into biological tissues, the frequency of which is above human hearing. It was reported to be effective in accelerating tooth movement, reducing root resorption, wound healing, bone growth[49,50,51].

Nanomechanical sensors

To understand the force moment system nanomechanical sensors were used. They can be incorporated in the bracket base to provide a real time feedback about the applied orthodontic force and to adjust it within a biological range[52].

Gene therapy & Nanotechnology

Of late specific vascular growth inducting genes in the growth of mandible have been mentioned in the literature but further clinical trials have to be done to ensure the safety, reliability and role of gene therapy in the field of orthodontics[53,54].

Nanorobots

Nanorobots may be used for manipulation of tissues directly at nano level and research has begun on the use of nanorobotics for medical applications like drug delivery, management of aneurysms and tumors. The theory of use of such nanorobots could be extended to dentistry and orthodontics in distant future, where nanorobots with specific motility mechanisms would navigate through periodontium to remodel it directly allowing accelerated orthodontic tooth movement[55,56,57].

MEMS/NEMS

The science and technology of operating at the micro scale level for biological and biomedical applications, which may or may not include any electronic or mechanical functions is known as Biomedical Microelectromechanical systems (Bio MEMS)[58]. Devices integrating electrical and mechanical functionality on the nanoscale level are Nanoelectromechanical systems (NEMS). Biocatalytic fuel cells (enzyme batteries) can be used to generate electricity which in turn helps in orthodontic tooth movement[59]. So to enhance orthodontic tooth movement MEMS/NEMS based system will be applied over the next few years, which can be safely implanted in the alveolus of the maxilla or mandible[60].

Toxicity

Dental materials remain in the oral cavity for a long duration of time, there is a high probability that the nanoparticles from these materials may leach out into the saliva and produce systemic effects[61]. In the oral environment they undergo biodegradation which includes both destruction and dissolution in saliva as well as chemical/physical destruction[62]. Various parameters like size, surface area, surface characteristics, stability, and routes of exposure of the nanoparticles determines the toxicity[63].

Conclusion

Nanometals and their oxides have numerous applications in dentistry owing to their favourable antimicrobial, mechanical and regenerative properties. Nanotechnology can be utilized in various stages of orthodontic treatment procedure in order to achieve more favourable and faster treatment outcome. Orthodontic treatment may thus be painless, effortless with the help of nanotechnology, providing an improved quality of patient care. A lot has still to be done in this direction to reach such goals with evidence.

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