EC DENTAL SCIENCE
Review Article

Nano-Orthodontics: Small is the New Big

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Abstract

The inquisitive nature of mankind has lead to an interest in the process of scientific methodology. Science is undergoing yet another change with the increased research in the field of nanotechnology. Many researches have been done in the field of nanotechnology that have influenced the approach to dentistry. As we enter the era of nanotechnology, it is interesting to follow this new thought of exploring the tiny little details of all substance. The approach of manipulation of materials at nanoscale can give a whole new dimension to orthodontic treatment modalities. This review article is an effort to throw some light on the various recent advances and the upcoming researches that can be an influence on the conventional orthodontic treatment followed by orthodontists worldwide. With the use of nanotechnology in various aspects of orthodontics, it is expected to speed up the lengthy treatment time and reduce effort of the orthodontist to bring about efficient and effective treatment results.

Keywords: *Nano Adhesives; Nano Particles; Nano Coated Archwires; Nanorobots; Dental Biomimetics*

Introduction

The prefix nano has originated from the Greek word nannos meaning dwarf [1]. A nanometer is one billionth of a meter. The principle of nanotechnology is using individual atoms and molecules in the construction of functional structures [2].

The concept of nanotechnology was first addressed in 1959 by the physicist Richard P Feynman in his lecture "There's plenty of room at the bottom" and explored the possibility of manipulating materials at the scale of atoms and molecules. He proposed to develop a wide range of automatically precise microscopic instrumentation from nanomachines, nanorobots and nanodevices that were manufactured by machines all the way down to the atomic level [3]. The term nano-technology was first used in 1974 by Norio Taniguchi, a researcher who used it to refer to the ability to engineer materials precisely at the nanometer level [4]. The term nanotechnology was first coined by Prof. K Eric Drexler in 1986 in his book "Engines of Creation" [5].

According to the definition of the National Nanotechnology Initiative, nanotechnology is the direct manipulation of materials at the nanoscale [6]. Nanotechnology is related to design characterization, production and applications of structures, devices and systems by controlling shape and size at nanometer scale [7]. Freitas [8] defined nanodentistry as the science and technology that will make possible the maintenance of comprehensive oral health by employing use of nanomaterials, biotechnology including tissue engineering and dental nanorobotics.

It is used in medicine (healthcare, diagnostics, drug development and delivery, tissue engineering, genomics), chemistry and environment, reduction of energy consumption, information and communication and heavy industry [9].

Two ways to produce nanomaterials are:

1. Top-down approach: It starts with a bulk material and then breaks it into smaller pieces using mechanical, chemical or other form of energy.
2. Bottom-up approach: It synthesizes the material from atomic or molecular species via chemical reactions, allowing for the pre cursor particles to grow in size [1].

Application in Orthodontics

Nano-adhesives

Nanoadhesives are nanosolutions with filler-particle sizes of ≤ 100 nm, used for bonding orthodontic appliances. Nanocomposites are prepared by adding nano sized filler into composites by the process of Flame pyrolysis, Flame spray pyrolysis or Sol-gel Process. Nanofillers can be of 2 types, nanoparticles or nanoclusters [10]. Reduced filler particle size helps in increasing the filler load that reduces the polymerization shrinkage and thus increasing the strength of material [10]. Beun., *et al.* [9] compared the physical properties of nanofilled, universal hybrid and microfilled composites, and observed a higher elastic modulus with the nanofilled RBC than most of the hybrids tested.

Advantages of using nanoadhesives include higher dentin and enamel bond strength, high stress absorption, longer shelf life, durable marginal seal, no separate etching required and fluoride release [11].

Felemban NH and Ebrahim MI [12] examined the effect of adding different concentrations of ZrO2-TiO2 nanoparticles to orthodontic adhesives which showed increased compressive strength, tensile strength and shear bond strength. Uysal., *et al.* [13] evaluated the bond strength of nanocomposites and showed that nanomaterials are suitable for bonding as they fulfil the suggested SBS ranges for them to be clinically acceptable. Sadegh., *et al*. [10] concluded that nanocomposites had better bond strength than conventional composites. Yamagata S., *et al.* [14] Suggested the introduction of Eu3+ -doped ZnO nanoparticles into orthodontic adhesives to make them visible for their safer and complete removal after orthodontic treatment. Mitra., *et al*. [15] reported that the nanocomposites showed high translucency, high polish and polish retention to those of microfills while maintaining physical properties and wear resistance.

Antimicrobial Agents

Orthodontic appliances may interfere with the self-cleaning ability of teeth and lead to altered oral microflora and increased levels of acidogenic *Streptococci* mutans and *Lactobacilli* in saliva. This causes formation of cariogenic biofilm and plaque that leads to dental decay [16]. To avoid enamel demineralization, antimicrobial agents like Silver and Titanium dioxide may be used in composites and glass ionomer cements [10]. Nanoparticles present a large surface-to-volume ratio, thus a large surface area for antimicrobial activity by close interaction with microbial membranes [17]. With bacterial strains increasingly becoming resistant to antibiotic, they are less likely to become nanoparticle resistant [18]. Also, metal nanoparticles show highly bactericidal activity [17].

Ahn., *et al.* [19] showed that bacterial adhesion to silver nanoparticles is less than conventional composites. Thus, can prevent enamel demineralization. Lackovic., *et al.* [10] suggested that attachment of Streptococcus mutans to silver nanoparticles was reduced and thus less biofilm formation. Elaska., *et al.* [20] concluded that improved antibacterial and mechanical properties were seen in Titanium dioxide incorporated GIC. Poosti., *et al.* [21] reported that adding titanium oxide (TiO_2) nanoparticles to orthodontic composite enhances its antibacterial effects without compromising the shear bond strength. Alt., *et al*. [22] reported that polymethylmetacrylate bone cement loaded with silver particles (nanosilver) showed high effectiveness against multiresistant bacteria.

Coating of orthodontic brackets with a thin film of nitrogen-doped titanium dioxide nanoparticles also shows antimicrobial properties. They resist biofilm formation due to increased hydrophilicity. Cao., et al. reported that TiO_2 nanoparticles show good anti-adhesive property against *S. mutans* and antimicrobial activity through visible light [16].

Mattick., *et al.* [23] showed that the use of fluoride-releasing elastomers significantly reduced demineralization during orthodontic treatment. Wilson, Gregory [24] found a significant reduction of *S. mutans* in saliva in the first week in their experimental group, which demonstrated the antibacterial action of the elastomeric e-chain.

Lin., *et al.* [25] reported that the fluoride releasing capacity of RMGIC improved by incorporating Nano Fluorapatite or fluorohydroxyapatite. According to Enan and Hammad [26], bands cemented with Nano hydroxyapatite modified GIC showed reduced microleakage as compared to conventional GIC.

Enamel Remineralisation (Dental Biomimetics)

Orthodontic treatment requires a firm anchorage to hold and move other teeth. Enamel demineralization adjacent to bands and brackets is a major drawback for anchorage requirement [26]. An interesting venue for speculation on the enamel remineralization is that of nanotechnology mimicking processes that occur in nature (biomimetics) [1]. Major tooth repair may be possible through combination of nanotechnology, genetic engineering and tissue engineering where all the lost tooth structure can be replaced with the remanufactured tooth structure to the best esthetic standard [11]. Calcium nanophosphate crystals, which are less than 100nm, organised in crystalline form of hydroxyapatite have been developed recently. They have increased surface area and wettability and thus, increased bioactivity. This leads to release of calcium, phosphate and fluoride ions that are organised in fluorapatite and calcium fluoride on the demineralised surface of tooth [10].

Chen., *et al*. [27] used highly organized micro architectural units of nanorod-like calcium hydroxyapatite crystals arranged roughly parallel to each other to simulate the natural biomineralization process of dental enamel formation. Medeiros., *et al.* [28] showed that calcium nanophosphate provides erosion resistance by forming a protective layer on enamel surface. Carvelho., *et al.* [29] concluded that it was a better remineralizing agent for eroded enamel surface than CCP-APP paste.

Nano coated archwires

When a tooth slides along the archwire, there is friction between the bracket slot and archwire. This may cause difficulty in tooth movement which increases the treatment time. To overcome the friction, heavy forces may be applied. But, this can cause anchorage loss and root resorption. Thus, a need to reduce this friction arises. This can be achieved by coating the wire with nanoparticles to allow easy sliding of bracket on wire and efficient tooth movement [30]. Katz., *et al*. [30] recommended the use of self-lubricating coating containing fullerene-like tungsten disulfide (IF-WS2) nanoparticles as a dry lubricant on the orthodontic wires. The presence of WS_2 nano-sheets at the interface of two metals under high loads, leads to a very facile sliding between these sheets thereby reducing the coefficient of friction.

Orthodontic Brackets

A new material containing hard alumina nanoparticles embedded in polysulfone was introduced by UC3M for making orthodontic brackets. The rigidity of the material increases the strength of the brackets. This material reduces frictional and mechanical resistance of the brackets to orthodontic wires along with maintaining the transparency of the brackets. It has the properties of strength, reduced friction and biocompatibility [10].

To bring about efficient tooth movement along with reduction of traumatic side effects, it is necessary to assess the amount of forces and moments that are applied on the teeth. With the use of nanotechnology, a new concept of brackets with integrated microelectronic chip equipped with multiple piezoresistive stress sensors for 3D force and moment measurement has been introduced [31]. Lapatki., *et al.* [32] constructed such a bracket 2.5 times the size of a conventional bracket incorporating a microelectromechanical system with 32 stress sensors distributed over the chip area and evaluated its ability to accurately calibrate the externally applied force-moment systems. They have advantages of (1) Simultaneous data acquisition for teeth included in the appliance; (2) all 6 components of the force-moment system(F_x, F_y, F_z, M_x, M_y, M_z) can be quantitatively determined; and (3) the forces and moments are measured directly at the location where the load is transmitted to the teeth; (4) the unknown, highly variable friction between bracket and archwire is accounted for.

This real-time feedback allows the orthodontist to adjust the applied force to be within a biological range to efficiently move teeth with minimal side effects [31].

Orthodontic Nanorobots

Recent studies have targeted at building biosensors and nano-kinetic devices required to enable nanorobotic operation and locomotion. Nanorobots in orthodontics may be used to attach to cells and manipulate them [33]. Therefore, highly accelerated tooth movement can be brought about by manipulation of the periodontal ligament, bone, cementum and gingival tissue. The process of leveling and alignment of teeth thus carried out by these nanorobots will be fast and painless [34].

Shape memory polymers

Shape memory polymers (SMPs) are materials that have the ability to memorize a macroscopic or equilibrium shape and then be manipulated and fixed to a temporary or dormant shape under specific conditions of temperature and stress. They can rapidly change from this temporary shape to their original (or permanent) shapes under appropriate stimulus such as temperature, light, electric field, magnetic field, pH, specific ions or enzyme. This relaxation to the original shape is accompanied by forces exerted to teeth which bring about orthodontic movement. Once placed in the mouth, these polymers can be activated by the body temperature or photoactive nanoparticles activated by light [35].

Carbon nanotubes or nanofibers and organic-exfoliated nanoclay are used as fillers as they improve mechanical strength and shape recovery stress of the SMPs. Nano SiC as a filler material can improve the elastic modulus of the SMPs [36].

They provide the advantages of providing a light, continuous force over long range that cause less pain, fewer visits and also are esthetically more pleasing as they complement tooth coloured brackets and stain resistant [36].

Nanoelectromechanical systems

Nanoelectromechanical systems (NEMS) are micromachined devices integrating electrical and mechanical functionality on the nanoscale level for application to biological systems [37]. Studies suggests that orthodontic tooth movement can be enhanced by supplementing the mechanical forces with electricity [38,39]. Animal experiments indicated that electric stimulation enhanced synthetic and secretory processes associated with accelerated bone remodelling [40]. It is expected that the NEMs based system can be applied to develop biocompatible powerful biofuel cells, which can be safely implanted in the alveolus of the maxilla or mandible to enhance orthodontic tooth movement [31].

Temporary anchorage devices

The temporary anchorage devices (TADs) are manufactured with smooth titanium surfaces because complete osseointegration is a disadvantage that complicates their removal. On the other hand, lack of osseointegration is also one of the factors for the failure of TADs. Therefore, a balance is required in the fabrication of an ideal surface that could stimulate initial osseointegration and facilitate its removal once the TAD is no longer needed. Biocompatible coatings like Titanium nanotubes should be studied to evaluate if it can enhance initial osseointegration and serve as an interfacial layer between the newly formed bone and the TAD [31,41].

Conclusion

Various advancements in the field of nanotechnology can introduce an entirely different approach to orthodontic treatment. The orthodontic treatment may thus be painless, effortless and fast with the help of nanotechnology providing improved quality of patient care. A lot has still to be done in this direction to reach to such goals.

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