Use of nanomaterials in orthodontics

Abstract:
Dentistry is revolutionised by introduction of newer materials and orthodontics is not an exception of it. Nanomaterials in orthodontics are now a days used from bonding materials to orthodontic wires. They not only modify the property of orthodontic bonding and enhancing the bond strength to decreasing friction of wires by nano coating reducing the force and thereby reducing side effects. Therefore this review article is aimed at covering all the nanomaterials uses in orthodontics.

Key-words: Nanomaterials, Nanodentistry, friction, microbial colonization.

Introduction:

Orthodontics is the branch of dentistry dealing with the prevention, diagnosis, management, and correction of mal-positioned teeth and jaws, as well as misaligned bite patterns. It may also address the modification of facial growth, known as dentofacialorthopedics. [1]Orthodontic therapy may include the use of fixed or removable appliances. Most orthodontic therapy is delivered using appliances that are fixed in place,for example, braces that are adhesively bonded to the teeth that provide greater mechanical control of the teeth; optimal treatment outcomes are improved by using fixed appliances.[1]It is one of the specialties in dentistry that has flourished enormously under research and development with the discovery of newer materials and diagnostic techniques.

Currently, we are exploring ways to improve the value of mechanical orthodontic appliances. The use of nanomaterials has partially solved this problem. The improvement of the biomechanical value of the orthodontic locks and arches and the interference with the bacterial flora by nanomaterials seems worth developing. Adding nanoparticles to the materials of appliances will become the gold standard, improving the quality of orthodontic treatment. In addition to determining the essential components of an orthodontic appliance, it will also be necessary to use appropriate proportions of nanoparticles in alloys.[2]

The term nano means dwarf in Greek. A nanometer is one billionth of a meter[2].

[3]Nanomaterials are widely used in orthodonticsand other clinical branches of dentistry due to their properties, such as antimicrobial properties and durability of materials. These particles do not exceed 100 nm, [3]resulting in a better surface area and mass ratio. The larger the surface area of the material, the greater its reactivity. [3]It is also easier to get absorbed in the body, which can result in high cytotoxicity.[3]

According to the European Commission[4] "Nanomaterial is defined as a natural, incidental, or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1–100 nm.[4]

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[5]The International Organization for Standardization (ISO) has provided definitions for "nanomaterial" and "nanoparticle." According to ISO's definition in 2010, a "nanomaterial" is a material with any external dimension at the nanoscale or having surface structures at the nanoscale. On the other hand, ISO's definition in 2008 characterizes a "nanoparticle" as a nano-object with all three external dimensions falling within the nanoscale size range. These materials may consist of grains, fibers, clusters, nanoholes, or a combination of these forms. Due to their significantly increased surface area per unit mass when compared to larger particles, nanomaterials (NPs) display distinct properties compared to other materials. This includes changes in the electrical, optical, magnetic, and other physical and chemical properties.[5]

The use of the described particles also gives better control of the anchorage. Better control results in better, more predictable treatment, which reduces the stress of the orthodontist and increases patient satisfaction. It will be possible to more accurately pursue the goals set at the beginning of treatment. A thorough treatment will improve the patient's quality of life after treatment. The level of compatibility remains a challenge for nanoparticles in the future.

Further research is required to determine the safety of their use. Overcoming this problem makes it possible to quickly increase the quality of orthodontic treatment. The use of nanoparticles will also reduce the described number of complications during orthodontic treatment, which will result in limiting the performance of additional procedures to eliminate complications. It also reduces treatment time, which reduces the cost of treatment. The shorter treatment time also allows more patients to be healed.

[3]Nanomaterials and nanotechnology have gained relevance in the field of orthodontics owing to their wide range of applications ranging from nanocoating in archwiresand brackets, orthodontic bonding, antimicrobial properties, shape memory polymers, mandibular growth stimulation with gene therapy and acceleration of orthodontic movement.[3] Nanotechnologies are applied in many fields, including medicine (nanomedicine) and dentistry (nano-dentistry).[4]Nanomedicine is the science of preventing, diagnosing, treating disease, and preserving and improving human health using nanosized particles. These innovations and research in this field aim to improve human life and health. [4]

[4]Nano-dentistry can be described as the science that uses nanostructured materials and technologies to diagnose, treat, and prevent oral and dental diseases. A common interest is to improve patients' oral health, decrease the invasiveness of treatments, and increase compliance with doctors. Conservative, endodontics, anesthesiology, aesthetics, and orthodontics are mainly involved.[4]

This article summarizes and describes the various uses of nanomaterials in orthodontics. The authors took care in reviewing the most recent literature, the most significant innovations in the orthodontic field, comparing different articles and literature reviews focusing the attention on the application of new nanomaterials and describing and summarizing the current use of nanoparticles and their antibacterial activity in orthodontics, including resin, brackets, and archwires.

Objectives of using nanomaterials in orthodontics:

Nanoparticles used in orthodontic materials are applied as a special coating on the surface of these materials to increase the antibacterial activity and enhance material surface properties.

Antibacterial activity:

Biofilm inhibition: [5]Biofilms are complicated communities created by a group of microorganisms. Biofilms act as the chief culprit in the etiopathogenesis of dental caries and periodontal disease. [5]Prolonged intraoral presence of orthodontic appliances are prone to plaque accumulation and increased biofilm adhesion posing challenges in maintaining oral hygiene, leading to periodontal infections such as gingivitis and periodontitis. Moreover, they can lead to demineralized lesions known as white spot lesions on the enamel surface.

[8]Inhibition of biofilm formation by nanoparticles as they adhere and permeate biofilms, affecting the ion channels and electrical signaling among the bacteria. This influences the membrane potential, resulting in diminished biofilm formation. [8]

Biofilm adhesion reduction using nanoparticles can modify material surfaces, making them unfavorable for biofilm adhesion.

Friction reduction and surface enhancement:

For many years, Different strategies have been sought in orthodontics to find solutions to reduce friction. First of all, the research focused on various designs for the brackets. Secondly, other archwire alloys and surface treatments were studied. It is easy to understand that the reduction of frictional force would be advantageous to reduce treatment time and the risk of root resorption, allowing greater control of the movements and the anchorage.[5]

During tooth movement in orthodontic treatment, brackets slide along an archwire, and a frictional force arises between the archwire's and bracket's surfaces against tooth movement. It has been shown that 60% of the orthodontic force applied is lost due to frictional forces.[5]

[5] There has been a growing emphasis on the modification of orthodontic brackets, archwires, and aligners through the application of surface nanocoatings. Methods like coating archwires and brackets with various nanomaterials such as Ag, Ti, TiO2, SiO2, titanium nitride (TiN), titanium aluminum nitride (TiAlN), zirconium nitride (ZrN), ZnO, molybdenum disulfide (MoS2), and diamond-like carbon (DLC)[5].[9]These coatings act as a dry lubricant and thus effectively reduce friction between two sliding surfaces without needing liquid lubricant. [9]

Let's talk about Associated microbial colonization.

Fixed orthodontic appliances inhibit oral hygiene and create new retentive areas for plaque and debris. It could increase the carriage of microbes and subsequent infection, and it is one of the common problems that should be avoided in orthodontic treatment.

The most common site for bacterial adhesion and biofilm formation is at the bracket adhesive junction, which is difficult to clean with daily brushing. The plaque accumulating around orthodontic brackets often results in enamel decalcification, white spot formation, and dental caries adjacent to brackets. It is also challenging to remove microbial growth around orthodontic appliances. The bracketed material largely contributes to its adherence to the fixed appliance and the design of orthodontic brackets and ligating methods. Many factors, including surface roughness and surface free energy, influence the quantity and quality of the plaque.[3]Electrostatic attraction and van der Waal forces influence the adhesion of microorganisms to surfaces, too. Many types of braces are used in orthodontics. Bonded brackets have many advantages over bands, such as better aesthetics, ease of placement and removal, and accessibility for oral hygiene.[3]

Application in orthodontics

Coated Brackets and archwires:

Brackets and archwires are the main instruments in fixed orthodontic treatment, and plaque and biofilm accumulation around the brackets can potentially lead to enamel demineralization. In addition, the rough surface structure of these instruments increases both the accumulation of microorganisms and the frictional forces. High frictional forces diminish treatment effectiveness, leading to slower movements and extended treatment time. [2]Nanoparticle-based dry lubricant coatings are used in wires and brackets to overcome frictional forces Inorganic fullerene, such as nanoparticles in tungsten sulfide, is a potent dry lubricant used as coatings on stainless steel wires.[2]

[6]One such study was conducted by Redlich et al. in which stainless steel wires and brackets were coated with nickel phosphorous electroless film impregnated with inorganic fullerene-like nanoparticles of tungsten disulfide IF-WS[2], which are potent dry lubricants. Incorporating cobalt and fullerene composite coatings, such as WS2 nanoparticles, into Ni–W–P alloy coatings has resulted in a lower coefficient of friction. Studies in which frictional forces were compared between coated and uncoated wires have shown a reduction in frictional forces by 51%–60% when coated archwires were used. The coefficient of friction was also found to be reduced significantly.

Other materials, such as carbon nitrile (CoNX), have been suggested, considering the possible toxicity of WS2. Coatings of zinc oxide (ZnO), inorganic fullerenes such as Molybdenum disulfide, diamond-like coatings, and nitrocarburizing have all been proposed. These coatings also improved the corrosion resistance of the wire.[6]

Figure (01) coated brackets and archwire

Jasso-Ruiz conducted a comprehensive assessment of various nanosilver-modified orthodontic brackets using radiomarkers to evaluate their anti-adherent and antibacterial properties. This study demonstrated that brackets coated with Ag NPs exhibit effective antibacterial activity against S. mutans and S. sobrinus. Moreover, it has been shown that brackets coated with Ag NPs can effectively inhibit plaque accumulation and prevent the onset of dental caries throughout the orthodontic treatment process. [5]Another investigation involving N-doped TiO_2-coated orthodontic brackets demonstrated that nanocoated brackets could effectively inhibit the growth of S. mutans for a minimum of 3 months[5], thereby providing efficient protection against enamel demineralization during orthodontic procedures.

[3]Nanoparticles are strategically applied to orthodontic archwires, acting as intermediaries to alleviate surface irregularities and mitigate frictional forces between the archwire and orthodontic bracket[3].[10] This further encompasses the prevention of metallic wire against oxidation. Thereby contributing to the objective of friction reduction. Orthodontic arches are made of non-precious metal alloys. The most common types of wire are SS, NiTi, and β-Ti alloy wires.[10]

This frictional force is proportional to the force with which the contacting surfaces are pressed against each other. It is governed by the interface surface characteristics (smooth/rough, chemically reactive/passive, or lubricant-modified). Minimizing the frictional forces between the orthodontic wire and brackets will accelerate the desired tooth movement and thus shorten the treatment time. [3]NiTi substrates can be coated with cobalt and a layer of IF-WS_2 nanoparticles using the electrodeposition method. The coated substrates showed friction reduction of up to 66% compared to the uncoated ones.[3]

Orthodontic elastomeric ligatures:

[5]Orthodontic elastomeric ligatures are synthetic elastic modules of polyurethane material with advantages such as quick application and patient comfort;[5]they are often a wise solution in clinical practice because they are inexpensive.

Figure (02) Elatomeric ties for wire ligation

[11,12]They act as a support to deliver nanoparticles that can be anti-cariogenic, anti-inflammatory, and antibacterial.[11] Research has shown that fluoride release is characterized by an initial burst of fluoride in the first few days, followed by a logarithmic fall. Therefore, Local delivery of therapeutic nanoparticles at areas of enamel decalcification, biofilm formation, and gingivitis might be highly beneficial.[12]

Orthodontic bands:

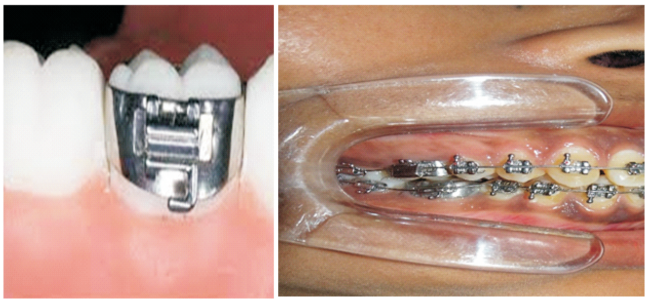


Figure (03) orthodontic bands on molars

[4]Fixed orthodontic treatment often requires the insertion of dental bands[4], which are appliances that surround the teeth circumferentially and are positioned supra gingivally.Clinical observations have frequently indicated an association between bands and gingival inflammation. Therefore, studies have been carried out, followed by coating orthodontic bands with nanoparticles to provide antibacterial properties to the band and use of seamless bands.

Nanomaterials in orthodontic adhesives:

The bonding system forms an integral part of successful orthodontic treatment. [2]Orthodontic resins contain adhesive and primer components that facilitate the attachment of orthodontic brackets to dental enamel through direct contact. There has been a continuous evolution in bonding materials and methods since Buonocore's advent of the acid etch technique in 1955[2].

Composites and glass ionomer cement are the two adhesive agents that secure bands and brackets to the teeth' surface.

[13]There are two classes of materials: nanoclusters (composites) and nanomers (glass ionomers). Further, the nanocomposites are of two types[13]: Nanofills-containing nanometer-sized particles (1–100 nm) all through the resin matrix with no large primary particles included nanohybrids consisting of larger particles (400–500 nm) with added nanometer-sized particles Because of the diminished size of filler particles, these can permeate the resin tags, an expanded

filler load can be accomplished bringing about decreased polymerization shrinkage, improved mechanical properties[14]. Similarly, a tremendous peripheral seal to dentin and polish can be achieved. The other advantages include excellent optical properties, easy handling characteristics, and superior polishability. Furthermore, the addition of nanofillers results in diminished surface roughness, thus reducing the odds of bacterial adhesion.

The most widely used Ag NPs have been incorporated into orthodontic adhesives and have been proven to exhibit significant antibacterial effects.[3]Although there is a consensus in the literature that Ag NP-integrated orthodontic adhesives exhibit high antimicrobial activity against microorganisms, such as Lactobacillus acidophilus, S. sanguinis, and S. mutans, there are different reports on which concentration is most effective[3].

Nanomaterials in orthodontics:

The various nanomaterials that have antimicrobial effects include chitosan, silver, and copper oxide, combined with composite and glass ionomers or used as coatings on surfaces.

Chitosan:

Chitosan is [15]a naturally acquired polysaccharide formed by the deacetylation of chitin. It is non-toxic, biodegradable, biocompatible, and has antibacterial properties[15]. Chitosan additionally has inhibiting action against fungi. This material's application as an antibacterial chemical agent in mouthwashes is limited due to its reduced solubility in water.Chitosanwhen added to composite and blended with zinc oxide in a concentration of 10% composite, results in decrease in biofilm creation.

Silver nanoparticles:

For years now, silver has been used to treat wounds and burns and is known to have an antimicrobial effect. Silver nanoparticles are added to orthodontic adhesives and coatings and are a material with excellent antimicrobial properties in various microorganisms. [16]The smaller AgNPs can release more silver ions, which promotes their antimicrobial effect. In contrast, the histological effect of AgNPs generally focuses on inhibiting microbial metabolism, leading to impaired production of extracellular polysaccharides and specific bacterial processes, leading to its general dysfunction. Silver nanoparticles may be helpful in compromised patients with immune deficiency, diabetes, or elevated risk of endocarditis.[16]

Copper nanoparticles:

Copper nanoparticles in copper oxide have been used in orthodontic adhesives.[17] According to studies, CuO can decrease biofilm formation by 70%- 80%.[17]It was also noted that curing time increased with the use of copper material when compared to silver.

Removable orthodontic appliances:

Acrylic:

PMMA-based orthodontic acrylic resins used to fabricate removable orthodontic appliances and retainers are conducive to accumulating microorganisms and forming biofilms due to their porous surface structure. Alongside the surface characteristics of these appliances,[5] inadequate oral hygiene practices of orthodontic patients also contribute to the accumulation of microorganisms and food remnants on the acrylic surfaces. Studies have shown that these PMMA-based orthodontic appliances increase the counts of microorganisms such as S. mutans and C. albicans within the oral cavity.[5][18] The addition of antibacterial NPs to removable acrylic orthodontic appliances and retainers is a method that can help reduce bacterial accumulation on the surfaces of these appliances[18].[19] In a randomized clinical study, Ghorbanzadeh found that patients using orthodontic appliances with Ag NPs had significantly reduced levels of cariogenic bacteria in their saliva, ranging from approximately 2–70 times (30.9% to 98.4%) lower than patients wearing regular appliances[19].

Clear aligners

Traditional removable orthodontic appliances made from acrylic resins recently replaced clear aligners made from a transparent polymer material. These clear aligners are becoming more popular among patients due to their enhanced comfort and aesthetic appeal compared with traditional appliances. During precise aligner treatment, both teeth and gums remain enclosed within the aligner throughout the day. Consequently, there is interest in enhancing the antibacterial properties of clear aligners through suitable NP modifications.

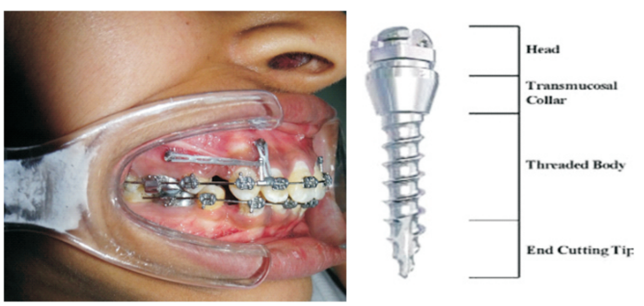
[5,20] In a study by Zhang et al., clear aligners were coated with antibacterial AuDAPT (AuNPs-Decorated Antimicrobial Peptide-Loaded Thermosensitive) materials. These coated aligners exhibited antibacterial effects against Porphyromonasgingivalis suspensions, slowed biofilm formation in neighboring areas, and demonstrated favorable biocompatibility.[20]

Temporary anchorage devices (TADs):

"A temporary anchorage device (TAD) is a device that is temporarily fixed to the bone to enhance orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether, and which is subsequently removed after use." Bone-based anchorage units include mini-screws, mini-plates, and mini-implants called temporary anchorage devices(TADs). At present, TADs are manufactured with a smooth surface to avoid osseointegration, but contrary to this, implant failure can occur due to a lack of osseointegration. Hence, TADs, which can provide an initial osseointegration and can be removed easily, will be ideal for orthodontic anchorage. [2]Titanium nanocoatings that can form an interfacial layer between the bone and TADs[2]are being studied and thus can enhance the initial osseointegration required for its success.

Mini-screws:

TADs generally find their stability mechanically (cortical or bicortical stabilization) and do not require biomechanical osseointegration. Currently, clinicians prefer to use mini-screws despite the higher success rate of mini plates. The miniplate placement procedure requires an oral surgeon, which is more invasive and expensive. Miniscrews are versatile: they are available in favorable sizes, simple to insert and remove, and affordable, and a skilled orthodontist can efficiently perform the procedure.[2] in the literature, different insertion sites have been described, both in



Figure(04) Micro-implants for orthodontic anchorage

The maxilla and mandible. They can be placed in the vestibular bone, inter radicular space, zygomatic buttress, symphysis, and hard palate. It is therefore essential to have a close intimacy between the bone and the surface of the miniscrew, as this allows better stability and more excellent resistance to orthodontic forces[2,14]. Furthermore, inflammatory processes can affect the primary stability and determine a premature loss of the screw. [2]Two studies have evaluated the stability and osseointegration of mini-screws surface modified by nanotechnology: the studied surface was characterized by $TiO2$ (titanium dioxide) nanotube arrays. The $TiO2$ nanotube arrays were loaded with RhBMP-2 (recombinant human bone morphogenetic protein-2) and ibuprofen and were compared with a control group of standard mini-screws. The effects of the drugs were evaluated in vivo: the study looked at how drug-modified mini-screws positively impacted tissue health. [2,21]These modified mini-screws can convey other drugs, such as antibiotic agents, aspirin, and Vitamin C, to decrease inflammation and patient discomfort at the insertion site. This modification to the materials has also proved crucial in ensuring greater surface roughness of the aids and improving wettability compared to conventional products.

Conclusions:

Nanotechnology plays an increasingly important role in dentistry, as it has the potential to bring significant innovations and benefits. Recent positive results in the field of orthodontics are encouraging for future research. Nanomaterials have introduced many advantages, mainly their mechanical and antibacterial properties. Coordinated and safe management of orthodontic treatment is crucial, and while there are limitations to dental materials and technical procedures, science and nanotechnology have helped to improve patient management. However, nanotechnology must continue to evolve to reach its full potential, as production technical difficulties and engineering problems still need to be wholly overcome. Further studies are necessary to develop entirely safe and biocompatible materials.

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