Nanotechnology in Orthodontics

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Abstract:
Nanotechnology has emerged as a transformative field in dentistry, particularly in orthodontics, due to its ability to manipulate materials at the molecular and atomic scale to enhance mechanical, biological, and functional properties. This review summarizes current advancements and potential applications of nanotechnology in orthodontics, focusing on nanomaterials, surface modifications, antimicrobial strategies, drug-delivery systems, and diagnostic innovations. Nanocoating's on orthodontic wires and brackets have shown improved frictional characteristics, increased corrosion resistance, and enhanced mechanical strength. Incorporation of nanoparticles into adhesives and elastomeric modules has demonstrated superior bond strength, reduced microbial colonization, and better colour stability. Despite significant promise, challenges remain regarding biocompatibility, long-term stability, cost-effectiveness, and regulatory approval. This review concludes that nanotechnology holds tremendous potential to revolutionize orthodontic practice, but further clinical studies are needed to ensure safety, optimize performance, and translate laboratory findings into routine clinical use.

Keywords: Nanotechnology, Orthodontics, Nanoparticle, Nanomaterial, Antimicrobial properties.

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INTRODUCTION

Nanotechnology is the study of modifying matter at the molecular and atomic levels. The word "Nano" is derived from "dwarf" in Greek. In 1959, American scientist and Nobel laureate Richard Feynman is credited with creating the concept and starting nanotechnology. He presented a paper titled "There is Plenty of Room at the Bottom" at the annual meeting of the American Physical Society at the California Institute of Technology on December 29, 1959.[1]

Eric Drexler's focus on the potential of molecular nanotechnology in the mid-1980s made this conceivable. The term "nano materials" was coined by N. Taniguchi, who defined them as substances with at least one dimension smaller than 100 nm.2 It is defined as an interdisciplinary field that concentrates on creating novel nano scale materials, devices, and systems. They stay below 100 nm because they obtain a better ratio of surface area to mass. These components may appear as nano holes, clusters, grains, or a combination of these. They are called quantum dots in three dimensions, sheets in one dimension, and nano wires and nano tubes in two.

The material's physical properties are significantly impacted by the fact that these new particles have a bigger surface area per unit mass than larger particles.3,4

Nanodentistry:
It is the science and technology of using nano materials, such as tissue engineering and nanorobots, to maintain almost perfect oral health.
Given that dentistry encompasses a wide range of interdisciplinary fields, all of which involve nanotechnology, including nanorobotics, nanoelectronics, and nanotechnology. Each of them has a distinct use in many dental specialties, such as biomechanics in orthodontics, local medication delivery and anesthetic in oral surgery and periodontal drug delivery, and enhanced diagnosis in oral medicine and diagnosis.[5,6]
Nanotechnology in Orthodontics:
Atomic force microscopy and nano indentation studies on orthodontic brackets and arch wires indicate that the surface characteristics of the brackets, including roughness and surface free energy (SFE), are crucial in reducing plaque development and friction. To examine An atomic force microscope (AFM) and a nanoindenter are used to examine the nano scale surface characteristics of biomaterials. Additionally, mechanical properties including as hardness, elastic modulus, yield strength, fracture toughness, and scratch resistance have been analyzed using nano indentation tests.7,8
Applications of Nanotechnology in Orthodontics
Nanoparticles in Elastomeric Ligatures:
Orthodontic elastomeric ligatures (OEM) are synthetic elastic polyurethane modules with characteristics like patient comfort and ease of application; they are often an affordable option in clinical practice.
Numerous studies have made an effort to highlight the correlations based on the chemical characteristics of various elastic ligatures and the need for modifications to lessen the negative effects of microbial biofilms on dental health. Fluoride-releasing ligatures have been the subject of some studies, but the findings have been conflicting and contradictory. Some highlight the long-term ineffectiveness associated with the ligatures' incapacity to ensure a prolonged release over time; they also seem to be ineffective even against decalcification. [9, 10]
It has been suggested that elastomeric ligatures could function as a support for the movement of nanoparticles, which could be compounds with antibacterial, anti-inflammatory, or anticariogenic qualities (like benzocaine) included into the matrix of elastomers.
Medicinal wax was also utilized. It has been shown that orthodontic brackets that release benzocaine gradually and constantly reduce the discomfort caused by mucosal irritation caused by the brackets. The most recent studies seem to evaluate the potential of ligature connection with silver nanoparticles, a material that appears to be able to combat dental biofilm and reduce the enamel demineralization caused by bacterial plaque formation without compromising the material's mechanical properties and, consequently, the effectiveness of orthodontic therapy.
The application of nanotechnology to dental materials is innovative in terms of improving results.Due to their anticariogenic qualities, silver particles may be produced by minimally invasive methods and have been incorporated into numerous products. It is commonly recognized that silver exhibits a cytotoxic effect on a range of microbes and is more antimicrobial than other metals:Although the precise mechanism is unknown, it most likely works by denaturing the enzymes involved in DNA synthesis and the respiratory cycle. Furthermore, Although the precise mechanism is unknown, it most likely works by denaturing the enzymes involved in DNA synthesis and the respiratory cycle. Furthermore,
Silver is safe and compatible with human cells. However, more investigation is now needed to determine whether they are truly biocompatible. [11, 12]
Application of Nanoparticles for Controlling Oral Biofilm in Orthodontics:
Brackets and fixed orthodontic appliances promote bacterial build up by providing retentive areas. Reports state that between 50 and 70 percent of individuals undergoing fixed orthodontic treatment. Enamel demineralization (white spot lesions or cavities) occurred around the brackets following appliance therapy.
Numerous strategies have been put out to reduce demineralization and the formation of white spots during therapy, many of which significantly rely on patient compliance. The cornerstones are the

elimination of mechanical plaque biofilm and the use of fluoride and/or antimicrobial treatments. To increase the resistance of enamel and dentine and stop the metabolism of the microorganisms that cause caries, fluoride is used in tooth paste, mouthwash, professional applications, and adhesives. Certain NPs have been introduced to orthodontic adhesives because of their biocidal or adhesion-resisting qualities to control the mouth biofilm. The main problem with adhesives and appliances when NPs are added to conventional orthodontic adhesives is that the failure to combine physical and chemical properties has a detrimental effect, leading to less-than-ideal clinical results. Additionally, the new product's security and antibacterial and sticky properties guaranteed nano-adhesives across a physiologically relevant surface pertinent time period.

Compounds containing NPs or covering the bracket surfaces NPs have been used to benefit from unique characteristics of specific NPs. 13. Additionally, by preventing the formation of biofilms, as should be shown in figure 4, nano-sized gold particles can be used on orthodontic devices like aligners to increase their antibacterial activity. Aligners cover the teeth and gingiva for almost the whole day, which increases the risk of plaque accumulation. Additionally, gold particles exhibit favorable biocompatibility in both in vitro and in vivo settings. [14]

Nanoparticles
1. Titania (Ti02)
2. Silver (Ag)
3. Gold (Au)
4. Silica (Si02)
5. Copper (Cu/Cu0)

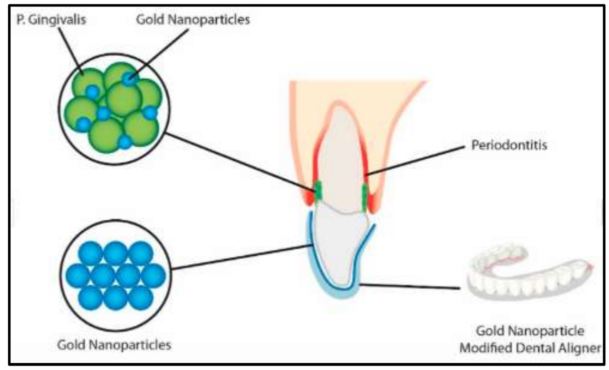

Figure 1: Aligners coated with modified gold nanoparticles causing enhanced antibacterial activity against Porphyromonas gingivalis. Due to presence of coated aligner, the number of bacterial cells was decreased, causing increased biofilm formation prevention.

Nanotechnology in Adhesives:

Nanomaterials can be used as adhesives in orthodontics to improve mechanical strength or reduce the possibility of enamel damage. The two adhesives that are most commonly used to affix bands and brackets to the surfaces of teeth are glass ionomer cements (GICs) and composites. Because of their superior mechanical properties and less potential for enamel damage, nanoparticles can be used as orthodontic adhesives. Two types of materials are nanomers (glass ionomers) and nanoclusters (composites).Furthermore, nanocomposites fall into two categories: Nanofills with nanometer-sized particles (1–100 nm) scattered throughout the resin matrix make up nanohybrids, which are composed of larger particles (400–500 nm) with additional nanometer-sized particles. [15, 16]

It is feasible to produce an increased filler load, which leads to less polymerization shrinkage and better mechanical properties, because the filler particles are smaller and can pass through the resin tags. Similar results can be obtained with a great peripheral seal to dentin and polish. The list of advantages is completed by excellent optical qualities, practical handling features, and polishability. Furthermore, adding nanofillers lessens surface roughness, which decreases the possibility of bacterial adhesion.

GIC is commonly used for band cementation in orthodontics due to its propensity to leak fluoride.The mechanical performance of traditional GIC was enhanced by the inclusion of fluorapatite polyacids, nano hydroxy, and N-vinyl pyrrolidone. Furthermore, it was shown that the biaxial flexural strength, diametral tensile strength, and compressive strength were greater than those of conventional GIC. A resin-modified GIC with high fluoride release and good mechanical properties was just released. Fluor aluminum glass and various nanofiller clusters are used to make it. [17, 18]

Orthodontic Power Chains:

Power chains have been used in every orthodontic office since their creation in the late 1960s. They are usually made of polymeric materials produced by the polymerization process, such as polyesters or polyether's. They provide light, continuous pressures, are inexpensive, easy to use, and facilitate patient adjustment, among other clinical advantages. They stand out for their exceptional adaptability and enhance the space closure of extraction scenarios. However, power chains offer drawbacks as well. Their mechanical performance has been demonstrated to be time-limited, requiring periodic replacement. However, power chains offer drawbacks as well. Their mechanical performance has been demonstrated to be time-limited, requiring periodic replacement. Both internal and external factors affect the strength of orthodontic power chains and decide whether permanent deformation takes place. The intrinsic factors are the material composition, production methods, and external morphology. External factors include the mouth cavity's temperature, pH, and moisture absorption. Because they absorb fluids from the oral cavity and have hydrophilic characteristics that allow them to discolor with time, they are less effective at maintaining oral health.[12]

In Orthodontic Archwires:

The frictional force that prevents the arch wires from moving presents several difficulties. It could also lead to tooth issues. By utilizing the right lubricants, these problems can be resolved. Nanotechnology has been applied to improve the properties of lubricants. Arch wires can be made to move more readily by lubricating them with materials based on nanotechnology. A self-lubricating coating with fullerene-like nanoparticles was used by Katz et al. The results showed that applying this lubricant decreased friction, which improved the arch wires' movement. The proper coating can reduce resistance to the movement of arch wires in addition to the use of lubricants.In one investigation, three wires composed of titanium molybdenum alloy, nickel-titanium, and stainless steel were coated with a uniform and smooth layer of nanoparticles (nanoceramics). Applying the coating was found to improve the surface topology, which lessens problems associated to friction. Orthodontic wires can be coated with a variety of nanoparticles to reduce friction force. Kachoei et al. coated stainless steel orthodontic wires with ZnO nanoparticles in the 40–45 nm size range. The addition of nanoparticles was shown to minimize friction between the wires and brackets by 51% when compared to reference wires. It was believed that the decreased friction was due to the nanoparticles' function as lubricants. [19, 20]

Shape Memory Polymers in Orthodontics:

The demand for beautiful orthodontic wires to complement tooth-colored brackets has increased significantly during the past ten years. It is possible to conduct research on shape memory attractive polymers. Shape memory polymers (SMPs) are materials that, after learning a macroscopic or equilibrium shape, can be changed and put to a transient or dormant shape under specific temperature and stress conditions. They can subsequently return to their initial, stress-free state under thermal, electrical, or environmental conditions. This relaxation is linked to the elastic deformation that was stored during previous manipulation. The SMP's return to its equilibrium shape may be accompanied by a macroscopic shape change that is helpful for ligation procedures or a sufficient and determined force that is advantageous for orthodontic tooth movement. Once in the mouth, these polymers may be activated by light-induced photoactive nanoparticles or body heat, which will move teeth. [21, 22]

Because SMP orthodontic wires will deliver lighter, more uniform forces than conventional orthodontic materials, patients may experience less discomfort.

Because the SMP materials are clear, colorable, and stain resistant, they also provide the patient with a more aesthetically pleasant appliance during treatment. Because of the SMP appliance's high percent elongation (up to about 300%), which allows for the continuous application of forces across a broad range of tooth movement, the patient requires fewer visits. [23, 24]

Nano Lipus Devices:

Low intensity pulse ultrasound, or LIPUS nanodevices, is a common therapeutic, surgical, and diagnostic technique in medicine. It is a form of mechanical energy that is transmitted as an acoustic pressure wave through and into biological tissues. It has been shown that low-intensity pulsed ultrasound (LIPUS) effectively improves angiogenesis during wound healing and releases preformed fibroblast growth factors from a macrophage-like cell line (U937).

Additionally, LIPUS has been demonstrated to enhance mandibular distraction osteogenesis, bone development into titanium porous-coated implants, and bone healing after fracture. It is still unclear how exactly US stimulation influences bone cell function. 25. El Bialy et al. applied LIPUS to the temporomandibular joint (TMJ) region of baboon monkeys and developing rabbits for a few minutes every day. 26, 27Their results showed that mandibular cartilaginous development had significantly increased. In a different study, Oyonartea et al. unilaterally stimulated experimental rats with LIPUS in the TMJ region for 10 or 20 minutes over the course of 20 days. The results showed that LIPUS treatment can affect rats' mandibular growth pattern by influencing the cartilage and bone levels. During orthodontic therapy, this strategy can also be employed to reduce root resorption. According to El-Bialy et al., LIPUS can improve the development of dental tissue in rabbits and may be used to cure root resorption. [28]

Biomems/Sems f or Orthodontic Teeth Movement

They are made up of silicon-based micromachined parts such gears, motors for biological systems, and rotary and linear motors. Nanoelectromechanical systems (NEMS) are nanoscale devices that combine mechanical and electrical functions. Evidence suggests that electrical pressures, in addition to mechanical ones, can enhance orthodontic tooth movement. It has been demonstrated that electric stimulation promotes tooth movement by raising cellular enzymatic phosphorylation activities and accelerating tooth movement in animal tests. Biomedical microelectromechanical systems (BioMEMS) are the science and technology of working at the microscale for biological and biomedical reasons, which may or may not include any electrical or mechanical functions. [29, 30]

When 15–20 microamperes of low direct current (dc) were applied to the alveolar bone by altering the bioelectric potential, it was discovered in animal experiments that osteoblasts and periodontal ligament cells had increased amounts of the second messengers cAMP and cGMP. These findings suggest that cellular enzymatic phosphorylation activities were elevated by electrical stimulation, leading to secretory and synthetic processes associated with accelerated bone remodeling. However, the intraoral source of energy is a major problem that needs to be fixed.[31,32]

Nano Remineralizing Agents:

White spot lesions and demineralization issues are common both during and after orthodontic treatment. Nanoparticles are being used to remineralize enamel that has lost calcium.Nanohydroxyapatite has been made into a paste. Because calcium nanophosphate crystals smaller than 100 nm increase the surface area and wettability of HA (hydroxyapatite) nanoparticles, the product has improved bioactivity and creates a protective layer that stops erosion on the enamel surface. [33]

Comparison of teeth demineralization development with and without nanoparticles' covered brackets.

Figure 2: Comparison of teeth demineralization development with and without nanoparticles covered brackets

Nanorobots:

By directly altering periodontal tissues, orthodontic nanorobots would enable quick tooth alignment. The idea of using such nanorobots in dentistry and orthodontics could be expanded in the far future. In these fields, nanorobots with specific motility mechanisms could move through periodontium and directly alter it, enabling faster orthodontic tooth movement. During orthodontic treatment, this strategy can also be employed to reduce root resorption. When it comes to solving issues like friction, which prevents teeth from aligning or retracting during treatment, nanotechnology has made significant progress. [34, 35]

Orthodontic nano robots enable quick tissue repair, painless tooth up righting, rotation, and vertical repositioning. A novel nanotechnology-based stainless-steel wire that combines exceptional strength with good deformability, corrosion resistance, and surface finish is being researched. In the future, periodontal tissues like gingival, periodontal ligament, cementum, and alveolar bone may be directly controlled by orthodontic nanorobots, enabling rapid and painless tooth alignment, rotation, and vertical repositioning in a matter of minutes to hours. Molar uprighting methods, on the other hand, require weeks or months to complete. [35]

Smart Brackets with Nanomechanical Sensors:

A idea for intelligent brackets with an integrated sensor system for measuring force and moment in three dimensions was recently released. Nanomechanical sensors can be included into the base of orthodontic brackets to provide the orthodontist with immediate feedback regarding the applied orthodontic forces. This will allow the orthodontist to successfully move teeth with the fewest possible negative effects by adjusting the applied force to be within a biological range.The primary advantages of smart brackets are the capacity to accurately manage teeth in all directions, move teeth more efficiently, spend less time at the chairside, and obtain treatment faster. 36, 37

Orthodontic Miniscrews

A tight proximity between the surface of the Mini screw and the bone is essential for greater stability and a stronger resistance to orthodontic forces. Additionally, the screw's primary stability may be harmed by inflammatory processes, which could lead to an early loss of strength. Two studies have evaluated the stability and osseointegration of nanotechnology-modified mini screw surfaces; arrays of TiO_2 (titanium dioxide) nanotubes were used to identify the surface. 38, 39The TiO_2 nanotube arrays were treated with ibuprofen and RhBMP-2 (recombinant human bone morphogenetic protein-2) before being compared to a control group of standard Mini screws. In order to evaluate the drugs' effects in vivo, the study looked at how drug-modified Mini screws enhanced tissue health. These modified Mini screws can also supply other drugs, like vitamin C, aspirin, and antibiotics, to reduce patient discomfort and edema at the insertion site. This modification to the materials has also proven essential in guaranteeing greater surface roughness of the aids and improved wettability as compared to standard products. [39]

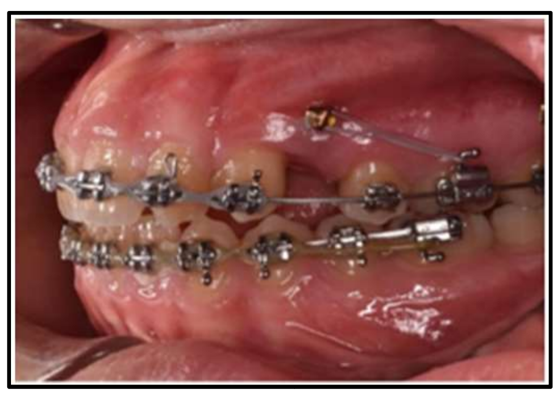

Figure 3

Nano silver Mouth Rinse

In order to prevent bacterial growth, the majority of mouthwashes often contain ethanol, which some patients with periodontal infections find uncomfortable. At incredibly low quantities, silver nanoparticles were added to an ethanol-free mouthwash and contrasted with reasonably priced mouthwashes. They noticed that there was no difference between the mouthwashes made with Silver Nano and other mouthwashes that were sold commercially.40

CONCLUSION

Nanotechnology now plays a larger and more constant role in the dentistry sector since it has the ability to bring about significant advances and benefits. Further research, especially in the field of orthodontics, must be sparked by the current positive results.

We have covered the several advantages that nanoparticles have provided to this sector, especially in relation to their mechanical and antimicrobial properties. The limitations of dental materials and technical techniques often refer to the fundamental objective of orthodontic treatment coordination and safety management; however, science and nanotechnology have helped to partially resolve some of these limitations, improving patient management in the clinical pathway

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