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Nanotechnology in Orthodontics: Its Present and Future-A Review

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Abstract

Nanotechnology involves manipulating matter at the nanometer scale, and this concept is being applied in both medicine and dentistry, referred to as Nanomedicine and Nanodentistry, respectively. It offers promising advancements in various areas, including enhanced diagnostics, targeted drug delivery, and biosensors. In dentistry, nanotechnology has numerous applications, ranging from diagnosing pathological conditions to local anesthesia, orthodontic tooth movement, and periodontics. Additionally, biomaterials science has significantly benefited from these technological advancements. This review offers an initial insight into the impact and future implications of nanotechnology in orthodontics.

Keywords: Nanoparticles, Nanomaterials, Recent advancement

Introduction

The term "nano" originates from the Greek word "nannos," meaning dwarf, and "nano" serves as a unit of measurement that captures this minute scale. The concept of nanotechnology was first introduced by physicist Richard P. Feynman in 1959. He envisioned the potential for nanomachines, nanorobots, and nanodevices to create precise microscopic tools and instruments. In 1980, K. Eric Drexler popularized the term, imagining the construction of machines at the molecular scale, such as tiny motors, robotic arms, and computers much smaller than a cell. Nanomaterials are defined as materials with at least one dimension smaller than 100 nanometers.

In recent years, nanotechnology has profoundly impacted the field of dentistry, offering significant potential to enhance oral healthcare through the use of nanomaterials and advanced clinical tools. This innovation increases the prospects for improved oral health delivery and ongoing maintenance through research focused on the diagnosis, treatment, and prevention of oral diseases.

Nanotechnology encompasses various nanostructures, which can take forms such as surface nano roughness, nanopits, nanomountains, or nanoparticles. The properties of materials at the nanoscale differ markedly from those at larger scales, primarily due to increased surface area and the so-called "quantum effect." This phenomenon occurs when particles are smaller than a certain size threshold, typically a few to several hundred nanometers, leading to deviations in their physical properties. At this scale, the particulate nature of matter—comprising molecules, atoms, ions, and electrons—becomes pronounced, especially in interactions with light.

The interdisciplinary nature of dentistry, which includes branches such as oral medicine, oral surgery, and orthodontics, has led to the integration of nanotechnology across various domains. This interdisciplinary field encompasses nano-robotics, nano-electronics, nanomaterials, and nano-biotechnology, each with distinct applications in dentistry. For example, nanotechnology can facilitate advanced diagnostics in oral medicine, enable localized drug delivery and anesthesia in oral surgery, and enhance biomechanics in orthodontics.

One of the most promising aspects of nanotechnology in dentistry is its potential to maintain comprehensive oral health. By employing nanomaterials, researchers are exploring biotechnology applications, including tissue engineering, and ultimately aiming for the development of dental nanorobotics. These innovations could transform the way dental professionals diagnose and treat diseases and injuries, paving the way for more effective and less invasive procedures.

Furthermore, ongoing research into nanotechnology is likely to yield new diagnostic tools and therapeutic strategies, enhancing the prevention and treatment of oral diseases. The capacity to manipulate materials at such a small scale opens avenues for creating smarter, more efficient solutions tailored to individual patient needs.

In conclusion, nanotechnology represents a revolutionary advancement in dentistry, with the potential to reshape oral healthcare delivery. By leveraging the unique properties of nanomaterials and integrating them into various dental practices, professionals can improve diagnosis, treatment, and overall patient outcomes. As research in this field continues to evolve, the future of dental care looks promising, with nanotechnology poised to play a pivotal role in enhancing oral health globally.[1]

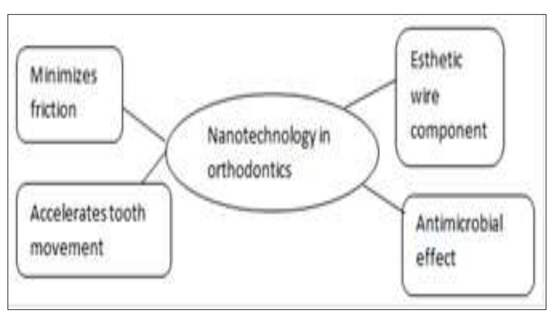

Figure 1:

Nanocoatings on orthodontic archwires aim to accelerate tooth movement by minimizing friction between the wire and brackets. Recent advancements utilize dry lubricants containing nanoparticles, which reduce friction without liquid media. Inorganic fullerene-like tungsten disulfide nanoparticles (IF-WS2) have been applied as self-lubricating coatings on stainless steel wires. A study demonstrated that stainless steel wire coated with a nickel-phosphorus electrolyte film impregnated with IF-WS2 nanoparticles showed significant friction reduction, with tests revealing decreases of up to 54%, leading to improved retention and stability during orthodontic treatment.

Polymer nanocomposites in orthodontic adhesives incorporate nanoparticles (0.005-0.01 microns) as fillers, enhancing mechanical properties like tensile strength and fracture resistance while reducing polymerization shrinkage. They also offer superior marginal sealing, optical properties, handling, and polishability compared to total-etch adhesives.

Elastomeric ligatures can act as carriers for nanoparticles, providing anticariogenic, anti-inflammatory, and antibiotic properties. Research shows that fluoride is released from these ligatures with an initial burst in the first few days, followed by a logarithmic decrease. Additionally, Gabriel et al. demonstrated the antibacterial effectiveness of silver nanoparticles against Streptococcus mutans in a 2009 in vitro study.[(2)]

Use of nanotechnology present and future in orthodontics:

1. **Nanoindentation and Atomic Force Microscopy Studies on Orthodontic Brackets and arch wires**

Orthodontic brackets can be metallic (stainless steel, titanium, gold) or tooth-colored (plastic, ceramic), with surface characteristics like roughness and surface free energy (SFE) significantly influencing friction and plaque formation. Micro- and nanoscale roughness can facilitate bacterial adhesion, and while new brackets are smoother, their surface properties may change during treatment.

To evaluate these nanoscale characteristics, a nano indenter combined with an atomic force microscope (AFM) is used. AFM, developed in 1986, scans a sharp cantilever tip across a sample to create detailed three-dimensional surface topographies, achieving resolutions of 1 nm laterally and 0.07 nm vertically. Studies utilizing AFM have shown that the surface roughness of orthodontic materials like stainless steel, beta-titanium, and nickel-titanium (Ni-Ti) wires impacts sliding mechanics, corrosion behavior, and aesthetics. Results indicated that while decontamination had no significant effect on Ni-Ti wires, it significantly affected stainless steel wires, highlighting AFM's role in monitoring nanoscale changes during orthodontic treatment.(2)

Recent advancements in orthodontics have seen the integration of nanoparticles into dry lubricants, which effectively reduce friction between sliding surfaces without the need for liquid media. Biocompatible nanoparticles, particularly inorganic fullerene-like tungsten disulfide (IF-WS2), have been applied as self-lubricating coatings on orthodontic stainless-steel wires to enhance their performance.

2. **Friction Reducing Nano Coatings On Orthodontic Arch Wires**

In a recent study, stainless-steel wires were coated with a nickel-phosphorus (Ni-P) film that was impregnated with IF-WS2. The coating process involved immersing the wires in solutions of Ni-P and IF-WS2, followed by analysis using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy. Tribological tests conducted with an Instron machine simulated the functioning of coated versus uncoated wires, revealing that the frictional forces on the coated wires were reduced by up to 54%. The friction coefficient dropped significantly from 0.25 to 0.08, indicating a marked improvement in performance.

Further investigations evaluated tungsten disulfide nanocoatings on nickel-titanium (Ni-Ti) substrates, where coatings of cobalt and IF-WS2 nanoparticles were applied through electrodeposition. These tests demonstrated up to a 66% reduction in the friction coefficient compared to uncoated substrates, suggesting significant potential for friction reduction in orthodontic applications involving Ni-Ti wires.

However, one concern with these coatings is the potential for allergic reactions in patients sensitive to nickel, necessitating biocompatibility evaluations of Ni-P coatings in animal models and subsequent human trials. Alternative materials have also been explored, including carbon nitrile (CoNX) due to potential toxicity concerns associated with WS2. Other suggested coatings include zinc oxide (ZnO), molybdenum disulfide, diamond-like coatings, and nitro carburizing, all of which have shown to improve corrosion resistance in orthodontic wires, offering additional benefits in clinical applications.[3,17]

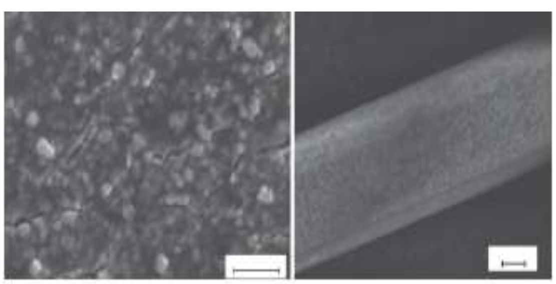

Figure 2:

3. Nanoparticles In Orthodontic Adhesives

Nanoparticles have become a significant component in dental composite materials, enhancing optical properties, mechanical strength, and wear resistance. Since the introduction of composite resins in the 1960s, the fundamental composition has remained consistent, comprising a monomer, silane-treated filler, and initiators. Initially, Bowen used milled quartz particles (8-12 µm) as fillers, but aesthetic limitations led to the development of minifilled composites in the 1970s with smaller silica particles (400 nm) that improved strength and polishability. However, microfilled composites (10-100 nm) were not suitable for high-stress areas due to their size not matching that of tooth structures, leading to the introduction of nanofilled composites.

Currently, two types of dental nanocomposites exist: nanofills, which use nanometer-sized particles throughout the matrix, and nanohybrids, which combine larger particles with nanometer-sized ones. Additionally, glass ionomer cement (GIC) is commonly used in orthodontics due to its biocompatibility and fluoride-releasing properties. While GIC is translucent and adheres well to moist tooth structures, its brittleness and lower mechanical strength have limitations.

Recent modifications to GIC, incorporating nanohydroxy and fluoroapatite, have shown improved mechanical properties, leading to greater compressive strength (CS) and diametral tensile strength (DTS). The introduction of light-curing nanoionomers, such as Ketact N100, has further enhanced fluoride release and mechanical properties. However, studies comparing shear bond strength between conventional composites and nanocomposites/nanoionomers found the former to be superior, indicating that while the latter may be suitable for bonding, they are inferior to traditional options.

A notable challenge in adhesive dentistry involves overhydrophilic bonding formulations that can compromise bond reliability. Recent research into nanogel-modified dentin adhesives demonstrated significant improvements in adhesive viscosity and bond strength when nanoparticles were integrated into traditional formulations. These studies highlight the ongoing evolution and importance of nanoscale-modified adhesive materials in enhancing the performance and reliability of orthodontic applications.

4. Nanoparticle Delivery From Orthodontic Elastomeric Ligatures

Orthodontic elastomeric ligatures (OEM) are synthetic polyurethane materials commonly used for their ease of application and patient comfort. However, they are prone to microbiological colonization, leading to increased bacterial plaque and potential enamel decalcification. Bacterial counts can rise significantly during treatment, with notable increases in Streptococcus mutans and Lactobacilli.

These ligatures can also serve as carriers for nanoparticles that provide anticariogenic, anti-inflammatory, and antibiotic benefits. Previous studies have shown that fluoride-releasing elastomeric ligatures experience an initial burst of fluoride release, which decreases logarithmically over time. Despite their potential, in vivo studies found no significant reduction in Streptococcus mutans colonies compared to conventional ligatures.

There is a lack of research on nanoparticle-based drug delivery from orthodontic ligatures to mitigate enamel decalcification and biofilm accumulation. Exploring local delivery of therapeutic nanoparticles could be beneficial, but **their release** rates, biocompatibility, and systemic toxicity must be thoroughly evaluated.

5. Shape Memory Polymer

In recent years, there has been growing interest in aesthetic orthodontic wires, particularly shape-memory polymers (SMPs). These materials can "memorize" a permanent shape and return to it under specific conditions like temperature or external stimuli. Various types of SMPs, including polyacrylate copolymers and segmented polyurethanes, have been explored in orthodontics. A systematic review highlighted that 51% of patents related to SMPs in dentistry focus on orthodontic applications, such as archwires, clear aligners, and elastic modules.

6. Nanorobots

In 2000, Freitas proposed that nanorobots could play a significant role in dentistry, enabling functions such as oral anesthesia, drug delivery, nanorobotic toothpaste, and tooth movement. These nanorobots would navigate through human tissues and adapt to their surroundings based on pre-programmed instructions from an onboard nanocomputer. In orthodontics, they could facilitate rapid and painless tooth repositioning within minutes to hours by directly interacting with periodontal tissues. However, it’s important to recognize that the rate of orthodontic tooth movement is primarily influenced by inflammation and bone remodeling, making the prospect of achieving such rapid movement appear futuristic, given the time needed for the biological adaptation and remodeling processes involved in orthodontic treatment.

7. Temporary Anchorage Device

Temporary anchorage devices (TADs) are typically made from smooth titanium surfaces (Ti6Al4V), as complete osseointegration complicates their removal, yet a lack of osseointegration can lead to TAD failure. The success of TADs relies on factors like initial mechanical stability and the quality of loading. Clinically, even smooth-surface TADs face challenges during removal due to increased osseointegration. To address this, researchers propose developing an ideal surface that promotes initial osseointegration while allowing for easier removal. A study by Zhou et al. (2010) explored nanoclay reinforced E-tricalcium phosphate (TCP) coatings on titanium miniscrews. Their findings indicated that such nanocoatings enhance TAD stability through increased nanoporosity and roughness, improving primary stability and partial osseointegration.(1,3,9)

8. Use Of Nanotechnology In Bio-Imaging

Recently, nanomaterials have sparked advancements in biomedical detection and imaging due to their unique passive, active, and physical targeting properties. Applications include:

- Fluorescence imaging with nanoparticles
- Nanometer-scale contrast agents for MRI
- Nanosized CT contrast agents
- Ultrasound contrast agents using nanoparticles

Compared to traditional contrast agents, nanoparticles have shown enhanced signal intensity, improved targeting capabilities, and longer circulation times in vitro and in animal models. However, most nano-contrast agents are still in the experimental phase, with very few having been tested in humans. In digital radiography, the development of nanophosphor scintillators has reduced radiation exposure while also improving image quality.(2)

9. Nanotechnology And Gene Therapy In Orthodontics

Gene therapy aims to modify gene expression to alter biological properties and has gained significant interest recently. Its success hinges on two key factors: the efficient and safe delivery of genes to target cells, and effective monitoring of modified cells via non-invasive imaging techniques. Magnetic nanoparticles have emerged as promising tools for gene delivery, facilitating approaches like magnetofection and theranostics, which combine therapy and diagnostics to enhance treatment efficacy and safety.

Cationic PEG-PLA nanoparticles are often used to deliver small interfering RNA (siRNA) for gene-specific knockdown. Despite progress, challenges remain for biodegradable nanoparticle-assisted cancer therapies. For instance, CALAA-01, an anti-tumor nanoparticle, faced dose-limiting toxicities in trials, while CRLX101 continues to show promise. The FDA approved Onpattro, the first siRNA nanodrug, for hereditary amyloidosis, demonstrating the potential of this approach.

Additionally, nanoparticles are being explored in stem cell therapy for neurological diseases. Although functional appliances (FAs) have been used to enhance mandibular growth, a recent review indicated that their effectiveness may not be clinically significant. Overall, while nanobiotechnology shows potential, its application beyond cancer treatment remains challenging. (1,3,6,7)

10. Nanofabricated Ultrasound Devices

Accelerating orthodontic tooth movement has been a focus of research for decades, with a recent emphasis on non-invasive techniques. Low-intensity pulsed ultrasound (LIPUS) has emerged as a promising method. Studies, including one by El-Baily et al., demonstrated that LIPUS could stimulate mandibular growth in patients with hemifacial microsomia, leading to significant clinical and radiographic improvements after a year of daily 20-minute applications. Another study indicated that LIPUS could minimize root resorption during orthodontic treatment, requiring similar daily applications against the gingiva for noticeable effects. However, patient compliance remains a significant challenge. To address this, there is a demand for a non-compliant LIPUS device that could function independently of patient participation. Research into creating a nanoscale intraoral LIPUS device with a built-in nanocircuit and nano-battery could enhance treatment consistency and effectiveness, representing a potential advancement in orthodontic care.

11. Nanomechanical Sensors For Orthodontic Forces And Moments Measurement- "Smart Brackets"

A stress mapping chip was developed using a 0.35 µm process, featuring micro coils created through gold electroplating within a photoresist mask. The chip incorporates twenty-four transistor-based stress sensors, designed to measure in-plane shear stress and the differences in in-plane normal stresses. This strategic distribution of sensors across the chip enables precise monitoring of forces applied to individual teeth during orthodontic treatment. The researchers concluded that this innovative system could facilitate the implementation of smart brackets in orthodontics, providing clinicians with real-time sensory feedback on the forces and moments exerted on each tooth. Such advancements could enhance treatment effectiveness while minimizing negative side effects, such as irreversible root resorption that can occur from excessive force application. Overall, this technology represents a significant step towards more precise and safer orthodontic care, aligning with the goal of optimizing patient outcomes through better force management.(1,10)

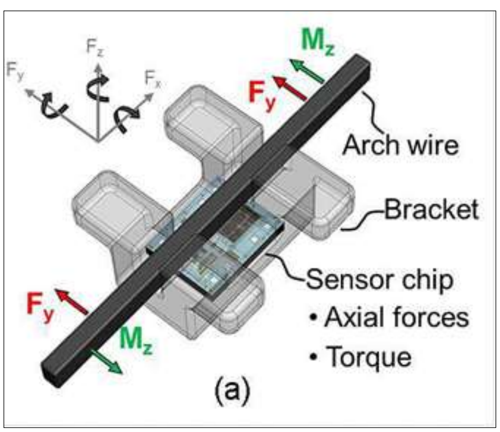

Figure 3: Smart brackets

12. Nanoparticles as antimicrobial agents

White spot lesions, a common consequence of orthodontic treatment, result from enamel demineralization around brackets or bands due to poor oral hygiene, leading to bacterial accumulation, caries, and gingival inflammation. To address this issue, various methods for prevention and treatment have been explored, with nanoparticles emerging as promising antimicrobial agents in dentistry due to their high surface-to-volume ratio, enhancing their interaction with microbial membranes.

Chitosan, a hydrophilic biopolymer derived from chitin, has demonstrated antimicrobial properties. A study by Mirhashemi et al. found that incorporating 10% chitosan with zinc oxide in composites significantly reduced biofilm formation.

Silver nanoparticles have been recognized for their long-standing antimicrobial effects, particularly in wound treatment. When added to orthodontic adhesives, they significantly reduced Streptococci adhesion. Optimal concentrations were found to be 1% and 5%, while 10% negatively affecte physical properties. Nanosilver coatings on orthodontic brackets also decreased plaque adherence, thus mitigating demineralization and white spot lesions.

Copper oxide nanoparticles have similarly shown promise; research by Toodehzaeim indicated that adding CuO to Transbond XT reduced S. mutans growth, with increased concentrations enhancing antimicrobial efficacy. Overall, these nanoparticles present viable options for preventing white spot lesions in orthodontic patients.

Conclusion

While the application of nanotechnology in orthodontics is still emerging, it shows great promise due to its wide range of applications. Currently, nanotechnology plays a vital and consistent role in dentistry, with the potential to drive significant innovations and improvements. Recent encouraging results should inspire further research, particularly in orthodontics. Incorporating nanoparticles into orthodontic materials can enhance their mechanical properties; for example, adding nanoparticles to adhesives can boost the mean shear bond strength from 12.06 MPa to 20.66 MPa. Additionally, certain nanoparticles, such as silver, serve as effective antimicrobial agents, significantly reducing microbial counts in orthodontic composite pastes from 69.1 to 8.2. Nanotechnology also excels in evaluating the properties of orthodontic tools, employing techniques like nano-indentation to assess surface roughness. Ultimately, while nanotechnology could transform medicine and dentistry, it also carries potential risks of misuse. The realization of its applications will depend on ongoing advancements, resources, and societal needs.

References

1. Dr Nithin VJoy, Dr Paridhi Gupta, Dr Jyothikiran H, Dr Raghunath N. 'Nanotechnology in Orthodontics- An Update'ISSN: 2350-0328
2. Dr. Moupriya Bera, et al. 'A Handbook on Nanodentistry- The Next Big Thing is Small' www.medicalandresearch.com
3. Madhurima Nanda, Dinesh Kumar Bagga, Poonam Agrawal, Sakshi Tiwari, Aartika Singh, Prashant Kumar Shahi. 'An Overview of Nanotechnological Advances in Orthodontics' 10.4103/ IJDS. IJDS_ 145_20
4. Soodeh Tahmasbi 1, Fatemeh Mohamadian 1*, Sehre Hosseini 2, Leila Eftekhar . 'A review on the applications of nanotechnology in orthodontics' 10.22038/nmj.2019.06.002
5. Panchali Batra1, Anam Mushtaq1, Jahirul mazumder2, Meryam S Rizvi2 and Ragini Miglani1 'Nanoparticles and their Applications in Orthodontics' ADOH.MS.ID.555584 (2016)
6. Dr. Deepti Govindankutty. 'Applications of nanotechnology in orthodontics and its future implications: A review' IJADS 2015; 1(4): 166-171 © 2015 IJADS
7. Nausheen Mobeen1, Shreya Kishore2, Rasiga Gandhi3 Sangeetha Duraisamy4, Ravi K. 'Biosafety of Nanoparticles Used in Orthodontics - A Literature Review' 10.14260/jemds/2021/543
8. Karishma Desai1,Jayalakshmi Somasundaram 2, Leslie Rani. 'Nanodentistry- An Overview'ISSN 2515-8260 Volume 07, Issue 01, 2020
9. Karthikeyan Subramani, Sarandeep Huja, G. Thomas Kluemper, Lorri Morford and James K. Hartsfield, Jr. 'Nanotechnology in Orthodontics_1: ThePast, Present, andaPerspective of theFuture'231 Nanobiomaterials in Clinical Dentistry. © 2013 ElsevierInc
10. Alberto De Stefani *, Giovanni Bruno , Giorgia Preo and Antonio Gracco. 'Application of Nanotechnology in Orthodontic Materials: A State-of-the-Art Review'10.3390/dj8040126
11. Dr. Arwa Saifee1, Dr. Sandhya Jain. ' Nanotechnology in Orthodontics – A Review' 10.36348/sjodr.2019.v04i11.007
12. ALI BORZABADI-FARAHANI, EBRAHIM BORZABADI & EDWARD LYNCH. 'Nanoparticles in orthodontics, a review of antimicrobial and anti-caries applications' 10.3109/ 00016357.2013.859728
13. Archana Bharadvaj, Abhishek Bharadvaj, Abhinav Misuriya, Suhani Maroli, S Manjula, Arvind Kumar Singh. ' Nanotechnology in dentistry present and future' journal of international oral health 2014:6(1):0-0

14. Wojciech Zakrzewski , Maciej Dobrzynski , Wojciech Dobrzynski , Anna Zawadzka-Knefel ,Mateusz Janecki , Karolina Kurek , Adam Lubojanski , Maria Szymonowicz , Zbigniew Rybak and Rafal J. Wiglusz. ‘Nanomaterials Application in Orthodontics’ 110.3390/nano11020337
15. Abiodun-Solanke IMF, Ajayi DM, Arigbede AO. ‘Nanotechnology and its Application in Dentistry’10.4103/2141-9248.141951
16. Pavan Kumar Pavagada Sreenivasalu , Chander Parkash Dora , Rajan Swami , Veeriah Chowdary Jasthi , Predeepkumar Narayanappa Shiroorkar, Sreeharsha Nagaraja , Syed Mohammed Basheeruddin Asdaq and Md. Khalid Anwer. ‘Nanomaterials in Dentistry: Current Applications and Future Scope’10.3390/nano12101676