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Nano-Orthodontics – A Literature Review

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Abstract:
Nanotechnology is redefining orthodontics by elevating material properties at the molecular scale. In orthodontics, nanocomposites, nano-coated wires, and brackets are being used to improve treatment outcomes. Nanocomposites provide strong, better durable, and aesthetically pleasing materials for braces and aligners. Nano-coated wires reduce friction, accelerating tooth movement and potentially shortening treatment durations. Improved adhesives offer stronger bonding, while self-cleaning and antibacterial nanomaterials help maintain oral hygiene and reduce infection risks during treatment.
Additionally, smart orthodontic devices utilizing nanotechnology can monitor treatment progress, allowing for more accurate adjustments. These innovations result in faster treatment times, enhanced comfort, better aesthetics, and increased effectiveness. As research in nanotechnology advances, orthodontic treatments are expected to evolve to become more personalized, efficient, and comfortable, ensuring superior patient care. Nanotechnology is transforming orthodontics, making it more effective, faster, and patient-friendly while reducing the workload for orthodontists.
Hence, it is crucial for orthodontists to enhance their skills and integrate these advanced material properties into their clinical practice.

Key Words: *Nano technology, nano dentistry, nano materials, orthodontics, nano robotics*

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I. Introduction

Nanomaterials, as the name suggests are materials which has particle size less than a 100nm.[1] Nanotechnology has a variety of uses in various areas or fields like drug delivery, and certain imaging techniques. The potential applications of nanotechnology are very extensive.[2] Over the last few years, nanotechnology in orthodontics has made the treatment procedures, efficient, fast, reliable, safe, and relatively less painful.[4]

The concept of nanotechnology was revealed in 1959 by the *physicist Richard P Feynman* in his lecture "There's plenty of room at the bottom". [3] Nano-technology as a term was first used in 1974 by *Norio Taniguchi*.[4]

2 Approaches to create nano-materials
Top-down approach[10]: It begins with a bulky material which is then broken down to smaller pieces either mechanically, chemically, or any other forms of energy.
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.

II. The Various Applications Of Nano Technology In Orthodontics In Detail:

Enamel remineralizing agents:

Enamel demineralisation is a frequently observed adverse effect during orthodontic treatment primarily due to challenges in maintaining effective oral hygiene. Hence, the use of enamel remineralising agents aid in restoring the damaged enamel.

Nano-hydroxyapatite (HA) has been a recent innovation in the field of nanotechnology that offers promising results in restoring demineralised enamel. Due to the nano particle size, there is increased surface area and wettability. On application, nano HA releases calcium, phosphate and fluoride which further reorganize into calcium fluoride and fluorapatite to strengthen the demineralised enamel.[3]

Medeiros et al. in their study in 2013 concluded that calcium nano phosphate forms a coating on the enamel surface and provides protection against erosion.[3]

Nano adhesives:

Nano adhesives are obtained by adding nano sized filler particles to the composite. This can be done either by the process of Flame pyrolysis, Flame spray pyrolysis, or Sol-gel Process.

Reduced filler particle size

Increases the filler load

Reduces the polymerization shrinkage

And hence increases the strength of the material.[5]

A study by Felemban NH and Ebrahim MI [5] reported that addition of different concentrations of zirconium oxide-titanium oxide particles to orthodontic adhesives enhanced its compressive, tensile and shear bond strength.

Mitra., et al. in their study showed that nanocomposites had a higher translucency, polish, and retention than micro filled composites while still maintained their physical properties. [5]

Control of biofilm - Nanoparticles in Orthodontic Adhesives for Improved Oral Health

To overcome the issue of plaque buildup due to accumulation of food particles around the brackets investigators have analysed that the use of nanoparticles with certain antibacterial properties such as titanium dioxide, silicon dioxide, and silver nanoparticles in adhesives .[14]

Studies have also demonstrated that adding titanium dioxide nanoparticles to orthodontic adhesives significantly enhances antibacterial effects for extended periods without affecting their physical and chemical integrity. Similarly, adhesives containing silver nanoparticles have shown a reasonable reduction in plaque formation and enamel demineralization, contributing to better oral health.[14]

Additionally, incorporating nanosized calcium carbonate particles in dentifrices has proven effective for enamel remineralization, further supporting overall dental hygiene.

Nano coatings in arch wires and brackets - Nanotechnology Solutions for Reducing Friction in Orthodontic Treatments

Frictional forces reduce the treatment efficiency by slowing down the tooth movement, and hence increasing the overall duration of fixed orthodontic treatment. To combat this issue, nano based dry lubricants are used as coatings.

In 2012, 3M introduced a novel orthodontic bracket material, which incorporated hard alumina nanoparticles embedded within a polysulfone matrix.[10] This innovative design also improved strength and biocompatibility.

Redlich et al.[12] in his study that he conducted showed a significant reduction in friction of friction between arch wires and brackets by the application a layer of nickel-phosphorous film with WS_2 nanoparticles on wires and brackets.

To address potential concerns over the toxicity of WS_2, alternative materials have been proposed. These include carbon nitrile (CoNX), zinc oxide (ZnO), molybdenum disulfide (MoS_2), and diamond-like coatings.[10]

Elastomeric Ligatures as Carriers for Nanoparticles in Orthodontics

It has been claimed that elastic ligatures can be used for the delivery of anti-bacterial medicines like benzocaine as nano sized particles, incorporated into the elastomeric matrix exhibiting anti inflammatory or anti cariogenic properties.[13]

Some studies analyse the association between ligatures and silver nanoparticles, an agent that seems to have the capacity to prevent enamel demineralization, without compromising the material's mechanical properties.[8]

Orthodontic bands - Advancements in Dental Materials for Preventing White Spot Lesions

Just like adding nano particles to adhesives, antimicrobial agents can also be incorporated into dental resins and cements to minimize the occurrence of white spot lesions and cavities while preserving the property of adhesion of the resin.[13] Zinc oxide, chlorhexidine, and fluoride particles help neutralize acids in the oral cavity and thereby decreasing bacterial activity. [8,13]

Orthodontic miniscrews

Precise engagement of the miniscrew into bone is vital for the stability of the implant to oppose the orthodontic forces. Inflammation around the implant can compromise the primary stability and potentially result in implant failure.

TiO2 (titanium dioxide) nanotube arrays[8] were utilized to study the surface of the implant. These nanotubes loaded with ibuprofen and recombinant human bone morphogenetic protein-2 (RhBMP-2), were compared to a control group of regular miniscrews.[13] The findings revealed that coated mini implants demonstrated enhanced stability. [20]

Additionally, another study investigated drug embedded miniscrews to evaluate their effectiveness in improving tissue health in order to assess the impact of the medications.[20] Other medications, such aspirin, vitamin C, and antibiotics, can be delivered by these modified miniscrews to reduce patient discomfort and insertion site irritation.

III. Future Advancements

Nanofabricated ultrasound device for orthodontics[9]

Research has demonstrated the potential of Low Intensity Pulse Ultrasound (LIPUS) to stimulate mandibular growth in both animals and human patients.[15] During a pilot clinical trial aimed at promoting mandibular growth in young adults with hemifacial microsomia, one of the significant challenges encountered was ensuring patients consistently held LIPUS transducers against their mandibular condyles for 20 mins daily over a period of atleast 1year to achieve noticeable improvement on the affected side. This requirement imposed a considerable burden to the patients and their parents. The LIPUS transducers measuring $3.5mm^3$, were not only large but also difficult to adjust, further complicating compliance. To address these issues there is a growing need for non-compliant LIPUS devices that can be placed directly into the patient's mouth. To develop such a self sufficient intra oral LIPUS, a nano circuit design can be utilized to create a primary operational circuit and the LIPUS transducer controller. Additionally, the device requires a nanofabricated battery to meet the power needs of this nano scale system.[6]

Nanomechanical sensors for orthodontic forces and moments measurements [9]

Orthodontic forces and moments constitute a complex force system influenced by factors such as the material properties of orthodontic wires, including their modulus and elasticity, and their geometry, which impacts stiffness. Additionally, variations in root lengths among individuals alter the moment arms and applied moments for efficient tooth movement while minimizing adverse effects like external apical root resorption(EARR). Researchers are working on developing advanced brackets. These brackets are designed to integrate three-dimensional mechanical sensors within their bases, enabling real time measurement of forces and moments. This technology would allow orthodontists to adjust forces dynamically, ensuring they remain within biologically safe thresholds.[6]

Recent literature has proposed the use of microsensors in orthodontics. In 2007, Lapatki et al[9] introduced a 'smart' bracket capable of measuring multi-dimensional forces and moments. Their work focussed on a large-scale prototype bracket that incorporated microsystem chip encapsulation.

Shape memory polymers

A category of smart materials referred to as shape memory polymers (SMPs) have a capability to fix in a momentarily preset shape and then regain it when exposed to external stimuli like heat, light, or a magnetic field. SMP can be used in both fixed and removable orthodontics. [10]

Depending on their intended use, these polymers can be engineered to have a broad variety of transition temperatures.[10] The patient may experience less discomfort as a result of the milder and more consistent forces. Further investigation into shape memory polymers to create aesthetically pleasing orthodontic wires holds great potential for the field of orthodontic biomaterial research.

Biological MEMS/NEMS[11]

Biological MEMS-(Micro Electro Mecahinical Systems) are an emerging field in research and medical micro devices. BioMEMS consist of micromachines, which include components such as gears, motors, and actuators capable of linear and rotary motion for the use in biological applications.[11]

The primary clinical applications of microdevices are in therapeutics, such as drug delivery systems, and diagnostics, including implanted sensors. Research suggests that orthodontic tooth movement may be enhanced by combining mechanical forces with electrical stimulation.[12] An enzymatic microbattery, which generates electrical energy from glucose, has been proposed as a potential solution to accelerate tooth movement. When positioned on the gingiva near the alveolar bone, this device could serve as an electrical force hotspot. Notably it operates without osseointegration, making it less invasive.[11]

However, there are still certain issues that need to be resolved, like soft tissue biocompatibility and how food with different pH and temperature affects a microfabricated protein battery's function.[11] It is extremely possible that orthodontic tooth movement can be improved in the coming years by using MEMS/NEMS-based devices.

Nanorobotics In Orthodontics[19]

Robotics for wire bending In orthodontic therapy- Accurate archwire bending plays a critical role in orthodontic treatment. Utilizing a robot with advanced posture control abilities can significantly enhance the precision and efficiency of archwire bending compared to conventional manual methods. [18]

Micro- and nanorobots Nanorobot-based toothpaste (Dentifrobots).[11] A sub-occlusal resident nanorobotic dentifrice that is administered via mouthwash or toothpaste may continually debride calculi while patrolling all supra and subgingival surfaces. These dentifrobots would be safe to consume, and able to be trained to clean teeth more efficiently. [19]

Adherence to the use of removable appliances is an issue that highly compromises treatment results. Electronic microsensors[19], like the Smart Retainer and the TheraMon, are sensors with promising results because they are simple to use. It is essential to have a reliable and accurate method to track the wear time of removable orthodontic appliances by detecting temperature variations.[16]

Automated Aligner Production Using Robotics In 2011, Hilliard patented a robotic system for creating features in orthodontic aligners. The current invention enables the addition of auxiliary devices that extend the duration, scope, and use of the application of polymeric shell orthodontic aligners to an automated activation feature and other feature installation procedure.

Certain challenges in nanotechnology

Certain challenges present as obstacles that must be overcome for the successful implementation of nanotechnology worldwide.

Few of those challenges are mentioned below in the table.[2]

Type	Barrier
Engineering	Feasibility of mass production technique Precise positioning and assembly of molecular scale parts Manipulating and coordinating activities of various microscale robots
Biological	Development of biofriendly nanomaterial Biocompatibility with all intricate parts of human body
Social	Ethics Public acceptance Regulation and human safety

IV. Nanotechnology: A Threat To Human Health?

There are some problems that need to be resolved because nanotechnology is a new field that is being explored. Potential risks resulting from nanotechnology may not manifest immediately because its long-term effects are unknown. In nature, nanoparticles are governed by their physical-chemical characteristics, quantity, and exposure duration. The following factors can further alter effects nanomaterials to the environment: pH, temperature, various biological conditions, and the presence of any adulterated components. Nanomaterials have the ability to change the soil, water, and atmosphere in this interaction, and they can be harmful to both the environment and human health.[2] According to reports, there are multiple ways for nanomaterials to infiltrate the human body.

The potential harmful effects of these materials on the human body, particularly through inhalation through the lungs, remains uncertain. Research by Yao et al (2013) & Zhang et al (2011) [11] highlighted concerns about environmental impact of nanotechnology, pointing to the risk of toxicological pollution due to unpredictable shapes, sizes and properties of nanomaterials.[4]

The solution to deal with this lies in recognizing the integration of technology and human tissues. The use of biocompatible nanomaterial coating and economical manufacturing procedure with advanced artificial intelligence for nanorobot functioning and development provides better outcomes and future aspects of nanotechnology while eliminating the need for conventional and invasive treatment modalities.[14]

V. Conclusion

The Integration of Nanotechnology in Orthodontics: A Step Toward the Future of Dentistry

Orthodontic treatment is sometimes challenged by the limitations of dental materials and technical methods. However, advancements in science and nanotechnology have addressed some of these challenges, enhancing patient care in the health care system. [13]

The evolution of nano orthodontics can bring about comprehensive changes, aiding the future of orthodontics incredibly, despite the fact that nanoparticles and their biosafety is of extreme concern.

However, it is equally important to address challenges such as scalability, cost, and long-term safety to ensure these cutting-edge advancements are accessible to all. By continuing to explore, the field of orthodontics can not only improve oral health but also enhance overall patient well-being, marking an exciting new era in dental science.

Finally, I would like to say it's time we move from macro to mini, micro, and now nano, ushering in a new era of precision. By adapting these innovations into orthodontic treatment, it has the potential to revolutionize oral health and enhance the overall quality of life.

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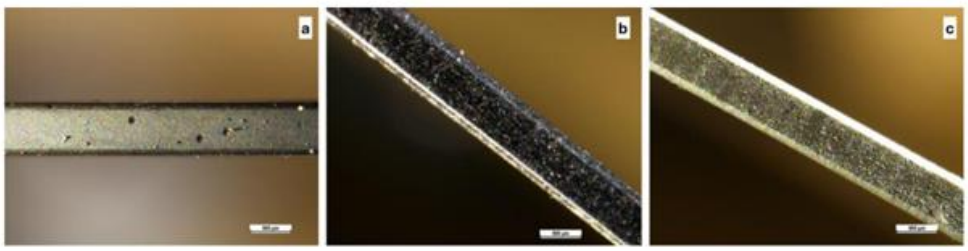

Stainless steel archwires- 0.19 X 0.25 coated with MoS2 (molybdenum disdulfide) and W2 (tungsten disulfide)
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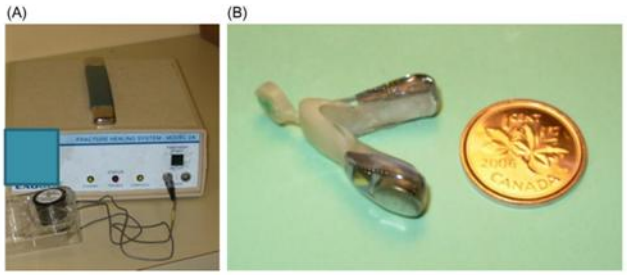

A – a large scale LIPUS device
B – a nanofabricated intraoral LIPUS device [6]