Nanotechnology in Orthodontics: A Review

Abstract:
Nanotechnology represents a groundbreaking advancement that has captured significant attention in the scientific community over recent decades. It is one of the fastest-evolving fields today, with broad applications across various industries, particularly in health care. This article provides an overview of the latest and most notable innovations in nanotechnology within dentistry, with a specific focus on orthodontics. Special emphasis is placed on the development and use of novel nanomaterials in the production of orthodontic elastomeric ligatures, power chains, and mini screws.

Key-words: Nanomaterials , Orthodontics, Brackets, Wires, Nanomedicine, Nanorobots Nanotechnology, Silver nanoparticle

Introduction:

Nanotechnology is the science of manipulating matter at the molecular and atomic levels. The word "nano" originates from the Greek word for "dwarf." The concept of nanotechnology was first proposed by American physicist and Nobel Laureate Richard Feynman in 1959, during a lecture titled "There's Plenty of Room at the Bottom," delivered at the American Physical Society's annual meeting at the California Institute of Technology. The idea gained significant traction in the mid-1980s, largely due to Eric Drexler's emphasis on the potential of molecular nanotechnology.

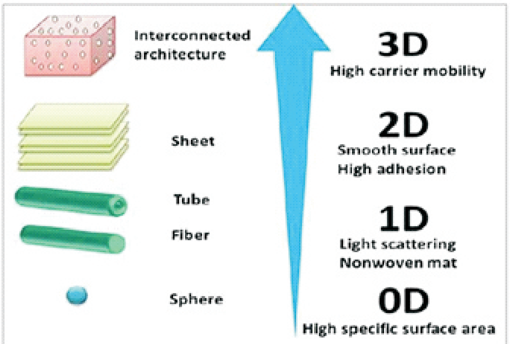
According to N. Taniguchi, who coined the term, nanomaterials are defined as substances with at least one dimension measuring less than 100 nanometers. Nanotechnology is an interdisciplinary field focused on developing new materials, devices, and systems at the nanoscale. These materials are engineered to remain under 100 nm because their high surface-to-mass ratio enhances physical and chemical properties. Nanostructures may take various forms, including grains, clusters, nanoholes, or combinations thereof. Depending on their dimensional structure, they are classified as sheets (1D), nanowires and nanotubes (2D), or quantum dots (3D), as shown in Figure 1.

This article aims to highlight and review the most recent developments in the application of nanotechnology within the field of orthodontics.

Access this article online

Website:
www.ujds.in

DOI:
https://doi.org/10.21276/ujds.2026.12.1.26



1. Nanodentistry :

Nanodentistry is the science and technology of achieving and maintaining near-perfect oral health through the use of nanomaterials, including tissue engineering and

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Received : 13 June, 2025, **Published :** 31 March, 2026

How to cite this article: Nayak, D. B., Bharti, C., Raotiwala, F., Jadon, J., & Mahato, D. S. (2026). Nanotechnology in Orthodontics: A Review. UNIVERSITY JOURNAL OF DENTAL SCIENCES, 12(1).

nanorobotics. As dentistry encompasses many interdisciplinary branches, nanotechnology is applied across various fields, integrating nanorobotics, nanoelectronics, and nanobiotechnology. Each of these components serves specific roles in different areas of dentistry—for example, advanced diagnostics in oral medicine, targeted drug delivery and anesthesia in oral surgery, localized periodontal treatment, and enhanced biomechanics in orthodontics.

2. Synthesis of Nanoparticles(NPs):

Method	Process involved	
Physical	Ball milling	Top-Down Approach
	Mechanochemical synthesis	
	Plasma vapor deposition	
	Laser pyrolyis	
	Inert gas condensation	
	Flame hydrolysis	
Chemical	Sol-gel or gel-sol conversions	Bottom-Up Approach
	Plasma/laser/flame enhanced chemical vapor deposition	
	Sol thermal synthesis	
Biological	Fungi	Intracellular
	Bacteria	Fig:.2 And
	Yeast	Extracellular
	Plant extracts	Synthesis

Fig. 1

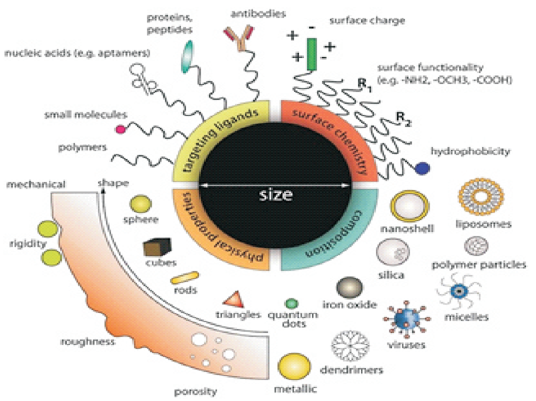


Fig. 2

3. The Impact of Nanotechnology on Orthodontics:

Nanoindentation and atomic force microscopy (AFM) have been widely used to study the surface properties of orthodontic brackets and archwires. These properties, including surface roughness and surface free energy (SFE), are important for reducing friction and plaque accumulation. Nanoindentation allows measurement of key mechanical characteristics such as hardness, elastic modulus, yield strength, and wear resistance. AFM, a high-resolution scanning probe technique, provides three-dimensional images of surfaces at the nanoscale. It uses a cantilever with a nanosharp tip that detects surface features through Van der Waals forces, measured by a laser and photodiode system, with feedback control to maintain a constant scanning force. AFM achieves lateral resolutions around 1 nm and vertical resolutions as fine as 0.07 nm, making it ideal for analyzing nanoscale features in orthodontic materials. Studies, such as those by D'Antè et al., have used AFM to evaluate the surface roughness of stainless steel, beta-titanium, and nickel-titanium wires, highlighting its high imaging precision. However, the main drawbacks of AFM are its small scan area and slow scanning speed, which can limit comprehensive analysis of larger samples.

5. Nanotechnology-based Approaches In Orthodontics:

a) Adhesives in Orthodontics :

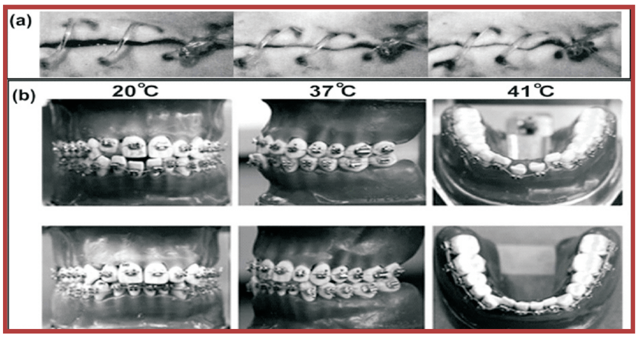
In orthodontics, nanomaterials enhance adhesives by improving mechanical strength and reducing enamel damage. Common adhesives like glass ionomer cements (GICs) and composites benefit from nanoparticles. Nanoclusters in composites and nanomers in GICs improve adhesive properties, with nanohybrids containing larger particles (400–500 nm) and nanofills (1–100 nm) offering better filler load and reduced polymerization shrinkage. This results in improved strength, peripheral sealing, and polishability. Nanofillers also reduce surface roughness, minimizing bacterial attachment. Fluoride-releasing GICs, often used for band cementation, are enhanced with materials like nano-hydroxyapatite and fluorapatite to improve mechanical performance and fluoride release.

b) Orthodontics power chains:

Since their introduction in the late 1960s, power chains, typically made from polymeric materials like polyesters or polyethers, have been widely used in orthodontics. They offer advantages such as affordability, ease of use, patient adjustability, and the application of light, continuous forces for space closure. However, their mechanical performance is limited over time, requiring frequent replacement. Their strength is influenced by internal factors (e.g., morphology, production, and material composition) and external factors (e.g., temperature, pH, and moisture absorption). Power chains are also prone to discoloration and can negatively affect oral health due to their hydrophilic nature. To improve their properties, a study in Taiwan used nanoimprinting to create nanopillars on the surface, converting the material from hydrophilic to hydrophobic, which helped address these issues and improved the overall performance.

c) Shape memory polymers:

In the past decade, there has been a growing demand for aesthetic orthodontic wires to complement tooth-colored brackets. Research into shape-memory polymers (SMPs) for orthodontics is promising. SMPs are materials that can "remember" and return to a pre-set shape when exposed to certain temperature, electrical, or environmental conditions. This shape change generates the necessary force for orthodontic tooth movement or ligation. SMP wires can be activated by body heat or light-induced photoactive nanoparticles to facilitate tooth movement. These wires offer several advantages over traditional materials, including the application of lighter, more consistent forces, reducing patient discomfort. SMPs are also clear, colorable, and stain-resistant, providing an aesthetically pleasing option throughout treatment. Additionally, their high elongation (up to 300%) allows for continuous forces over a wide range of tooth movement, reducing the need for frequent adjustments.(Fig-3)



d) Smart Brackets with Nanomechanical Sensors:

A recent development involves intelligent brackets equipped with an integrated sensor system for 3D force and moment measurement. Nanomechanical sensors embedded in the base of orthodontic brackets provide real-time feedback to orthodontists, allowing them to adjust forces within a biologically safe range (Fig-4). The key benefits of smart brackets include precise tooth movement in all directions, more efficient treatment, reduced chairside time, and faster overall treatment

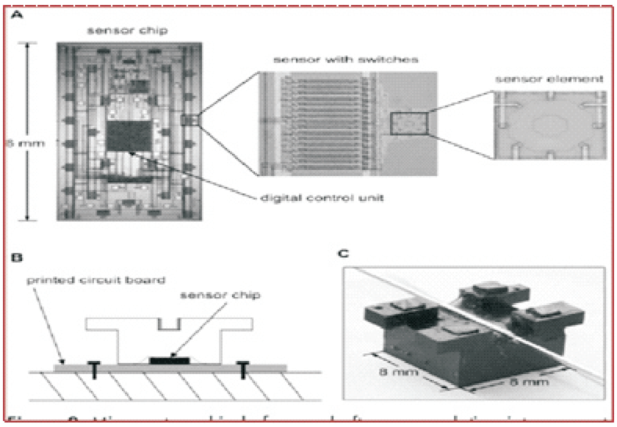


FIG-4

e) Orthodontics mini-screws:

Mini screw stability is crucial for orthodontic treatment, as close contact with bone enhances resistance to stresses. Nanotechnology-modified Mini screws with TiO2 nanotube surfaces have been studied, with RhBMP-2 and ibuprofen added to improve tissue health.(fig-5) These modified screws can also deliver medications like antibiotics and aspirin to reduce swelling and discomfort. Compared to standard screws, these modifications increase surface roughness and wettability, improving screw stability and performance

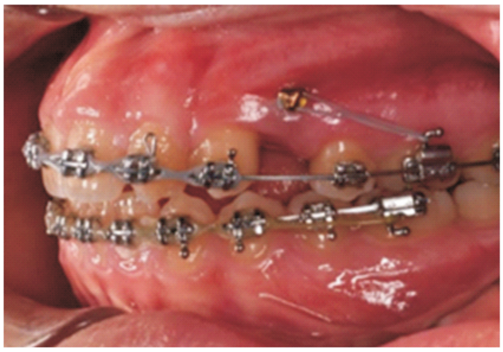


FIG-5

f) Elastomeric ligatures:

Orthodontic elastomeric ligatures (OEM) are elastic polyurethane modules used for their ease of application and patient comfort. However, they promote bacterial plaque accumulation, leading to enamel demineralization and increased bleeding. Studies have explored fluoride-releasing ligatures, but their long-term effectiveness is limited. Recent research suggests embedding nanoparticles, such as silver, into ligatures to combat biofilm and reduce enamel damage. Silver's antibacterial properties may help prevent plaque buildup without compromising the ligature's mechanical properties, though further research on biocompatibility is needed.

g) Controlling biofilms :

Fixed orthodontic appliances, including brackets, contribute to bacterial accumulation, leading to enamel demineralization (white spot lesions or cavities) in 50-70% of patients. To reduce this, methods such as plaque removal and fluoride or antimicrobial treatments are used, though they depend on patient compliance. Fluoride strengthens enamel and prevents bacterial metabolism. Certain nanoparticles (NPs) are incorporated into orthodontic adhesives to manage oral biofilm, but combining physical and chemical properties can impact clinical performance. Nano-adhesives provide longer-lasting antibacterial and adhesive qualities. Additionally, gold nanoparticles on aligners help prevent biofilm formation and show positive biocompatibility.(fig-6) Common NPs in orthodontics include titania (TiO2), silver (Ag), gold (Au), silica (SiO2), and copper (Cu/CuO).

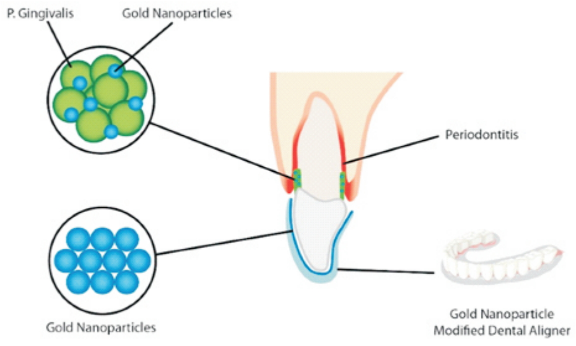


FIG-6

a) Archwires:

Friction between arch wires and brackets can hinder tooth movement and cause complications. Nanotechnology offers solutions by improving lubricants and coatings to reduce this resistance. (Fig-7)Nano-based lubricants, such as fullerene-like nanoparticles, have been shown to decrease friction and enhance wire movement. Additionally, applying smooth nanoceramic coatings to wires (stainless steel, nickel-titanium, titanium-molybdenum) improves surface texture and reduces friction. In one study, stainless steel wires coated with ZnO nanoparticles (40–45 nm) showed a 51% reduction in friction, highlighting the effectiveness of nanoparticles as lubricants.

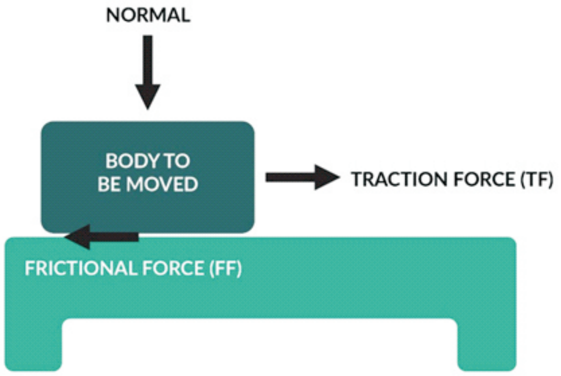


FIG-7

h) Nanorobots:

Orthodontic nanorobots hold future potential for rapidly aligning teeth by directly modifying periodontal tissues. These robots could navigate through the periodontium to enable faster, painless tooth movement and reduce complications like root resorption. They may also assist in tissue repair and allow precise repositioning—such as uprighting, rotation, and vertical adjustments—within hours rather than weeks. Additionally, advances in nanotechnology have led to the development of stainless-steel wires with high strength, flexibility, corrosion resistance, and improved surface finish, enhancing overall treatment efficiency

Conclusion:

Nanotechnology is increasingly influencing dentistry by offering significant improvements, especially in orthodontics. Its mechanical and antibacterial benefits have enhanced treatment effectiveness and patient care. While current advancements have addressed some limitations of traditional materials and techniques, further research is needed. Ongoing technical and manufacturing challenges must be overcome for nanotechnology to reach its full potential in clinical orthodontics.

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