# Nanoparticles in Orthodontics: A Review

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**Abstract**
The advent of nanotechnology has significantly impacted various fields of medicine, including orthodontics. This scientific study delves into the realm of nanotechnology and its implications in orthodontics. It explores various applications such as bolstering the antimicrobial properties of orthodontic resins to mitigate enamel demineralization and management of frictional forces during orthodontic procedures. This review discusses the application of nanoparticles in orthodontics, focusing on their benefits, types, and future prospects.

**Keywords**: Nanomaterials; Orthodontics; Brackets; Wires; Antimicrobial effect

## 1. Introduction

Orthodontics is a subspeciality of dentistry that focusses on the development of the face, the growth of the teeth and jaws, and the identification, prevention, analysis, and correction of abnormalities related to the jaws and mouth. Orthodontists can greatly benefit their patients by working with specialists in fields including periodontics, endodontics, prosthodontics, and oral and maxillofacial surgery. [1]

Traditional orthodontic materials and methods have certain drawbacks, such as susceptibility to bacterial colonization, inadequate mechanical properties, and delayed tissue healing. Nanotechnology, by the use of nanoparticles, presents opportunities to overcome these limitations, offering enhanced performance and improved clinical outcomes. Increased reactivity is due to the greater surface area since the size of the nanoparticles is within 100nm. High cytotoxicity is due to the reason that nanoparticles are easily absorbable by the human body [2]. Various dental specialists like orthodontists, endodontists, oral and maxillofacial surgeons, periodontists and prosthodontists make use of nanoparticle enhanced materials.[3]

The extended duration of wearing orthodontic brackets leads to increased dental plaque accumulation, which increases the risk of caries. This demineralization is referred to as the white spot lesion (WSL) resulting in caries. This is an indication that enamel surface demineralization is directly linked to full time wearing of orthodontic brackets and bands. [4] This occurs mainly due to the increased activity of cariogenic bacteria, which arises from extended plaque accumulation on tooth surfaces, nutritional deficiencies and diet.

Numerous studies have confirmed the rapid formation of WSL's during orthodontic treatment. Quite often this causes undesirable aesthetic changes that may require restorative treatment procedures. Research shows that there is a higher incidence of secondary caries around composite restorations. [5]

Technological advancements with nanosized materials results in enhanced mechanical, physico-chemical and antibacterial properties which is beneficial for both patients and orthodontists. Nanoparticles can also be utilized for a number of purposes such as coating of orthodontic wires, elastomeric ligatures, brackets and also for production of shape memory polymers and orthodontic bonding materials. These developments lead to a reduced treatment time by controlling biofilm formation therefore resulting in reduced bacterial activity. However, while nanotechnology presents numerous advantages in medicine, it also raises concerns about human and environmental safety. They can easily infiltrate the biological tissues and cause alteration at a molecular level. Therefore, comprehensive research on the detrimental effects of nanoparticles related to its toxicity is essential to evaluate risks and ensure their sustainable use.

## 2. Nano-particles and orthodontic arch-wires

When orthodontic wires and brackets rub against each other, it slows down the process of moving teeth and lengthens the duration of therapy. Dry lubricants, which mitigate sliding friction between solid surfaces without the need of a liquid medium, have had nanoparticles added to them as a countermeasure. As an example, orthodontic arch wires can make use of inorganic fullerene-like tungsten disulphide nanoparticles (IF-WS2). [6]

Atomic force microscopy (AFM) was used to assess the surface roughness of wires made of stainless steel (SS), beta-titanium (β-Ti), and nickel-titanium (NiTi). [7] Results showed that surface roughness affects sliding mechanics, corrosion behaviour, and the aesthetics of orthodontic arch-wires. Another area that was investigated utilising AFM in conjunction with a nano-indenter was the modulus of elasticity, hardness, and surface roughness of NiTi and stainless steel archwires. [8] Results showed that nanoparticles improved the archwires' surface and mechanical qualities while decreasing friction.

### 2.1. Nano-particles affecting friction in orthodontic arch-wires

Orthodontic brackets and archwires create a lot of friction, which limits tooth mobility. Tooth movement is hindered by friction, which happens at the contact surface of two moving things. The frictional force is affected by the interface properties and lubricants, and it is directly proportional to the amount of contact between the surfaces. Improved tooth mobility and shorter treatment times can be achieved by decreasing friction between orthodontic wires and brackets.

By employing the electrodeposition technique, cobalt and a coating of inorganic fullerene-like tungsten disulphide nanoparticles may be applied on NiTi archwires. When compared to traditional archwires, these coated wires reduced friction by as much as 66%. Nevertheless, nickel sensitivity can occur in certain individuals who are already at risk of allergic responses. So, it's important to conduct more experiments to determine if these nanoparticle coatings on archwires are biocompatible.

## 3. Delivery of Nano-particles

Elastomeric ligatures can serve as a framework for the delivery of nanoparticles that possess antibiotic and caries-preventing characteristics. There is published information on the release of fluoride, an anti-cariogenic agent, from elastomeric ligatures. [9,10]

There is usually a gradual decline in fluoride release from elastomeric ligatures after the initial increase in the first few days. As a result, demineralisation of the enamel around orthodontic brackets is less likely to occur throughout therapy. [11]

**4. Shape memory polymers and nano-particles**

When subjected to controlled temperatures and pressures, shape memory polymers (SMPs) can revert to their initial forms. This restitution is a result of the original manipulation's elastic deformation being released, which was induced by internal forces. Alterations in intraoral temperature trigger shape memory polymers. The force that is generated when SMPs are returned to their previous shape can be utilised for orthodontic tooth movement or to facilitate ligation processes through a macroscopic shape shift. Orthodontists find these materials more convenient to implant into patients' mouths due to their shape memory feature. [12]

With SMP orthodontic wires, patients are more likely to comply with treatment since the force is gentle and constant.

There has been a rise in the need for orthodontic archwires that improve aesthetics in recent years. For a more refined look during treatment, SMP orthodontic archwires are stain-resistant and diaphanous.

The increased elasticity of this material makes it possible to reduce the frequency of patient visits by providing uniform stresses over a broad range of tooth motions. [13,14]

**5. Oral Biofilm management using Nano-particles**

Because of their enormous surface area relative to their volume, nanoparticles are able to encircle microbial membranes and exert antimicrobial effects on a greater scale. Nanoparticles of metal, usually between 1 and 10 nm in size, work very well for this purpose. [15] Silver has a long history of use in medicine as a result of its antimicrobial properties. Incorporating nanoparticles into dental materials or applying them as surface coatings has allowed for the use of their antibacterial ability, which inhibits microbe adherence and reduces biofilm development. [16,17]

In their work, Ahn et al. contrasted three types of composite adhesives: two standard ones, an experimental one with nanofillers made of silica and silver, and a resin-modified glass ionomer (RMGI). The research tested these adhesives' antibacterial efficacy against streptococci that cause cavities, as well as their surface features and physical qualities. The ECA had a rougher surface than the regular adhesives because of the silver nanoparticles. When contrasted with more traditional adhesives, ECA showed significantly reduced bacterial adherence and microbiological development. However, when comparing the experimental and conventional composites, we found no discernible variations in shear bond strength or fracture resistance. [13]

**6. Nano-particles and brackets**

Orthodontists' technical performance is improved, and patients' functional, health, and cosmetic outcomes are boosted, thanks to advancements in the technology of orthodontic materials and products. Incorporating precise tip/torque values, being biocompatible, having a high resistance to fracture, a smooth slot surface to reduce friction and plaque accumulation, being resistant to corrosion, and having controlled release of ions are all properties that nanoparticle enhanced orthodontic brackets should possess. [18]

Brackets are typically made using one of three processes: casting, injection moulding, or milling. Brackets are made from a variety of materials, including as ceramics, metals, and polymers. Alloys including cobalt, chromium, titanium, gold, and platinum are among the most common metals used today. [19]

Plaque buildup is a potential issue with aligners since they cover the gums and teeth for the most of the day. Incorporating gold nanoparticles into aligners can increase their antibacterial effectiveness by blocking the production of biofilms.

As an eco-friendly substitute for stainless steel brackets, platinum-coated brackets are a great option. Platinum alloys have less friction than gold and stainless-steel alloys because they are more resistant to abrasion and corrosion.

When it comes to beauty and stability, ceramic brackets are among the best. Their biocompatibility, resistance to discolouration, high stiffness, and abrasion resistance are some of their well-known characteristics. Monocrystalline and polycrstalline ceramic brackets are distinguished by their manufacturing technique. [20]

Polycrystalline zirconia brackets have a number of advantages over other ceramics, such being opaque and showing inherent hues, and they also have a high level of fracture resistance. Less ominous and more aesthetically pleasing are monocrystalline alumina brackets. But because of the porosity, milling damage, and lack of internal grain boundaries, their fracture resistance is low. Some disadvantages of ceramic materials include a lower fracture resistance compared to metal, difficulties in bonding the bracket since the bracket borders are less visible, and the potential of iatrogenic enamel injury during the debonding operation.

## 7. Nano-particle coating in orthodontics

At every point in the orthodontic treatment process, friction is crucial to the movement of the teeth. The use of stronger treatment forces is one strategy for overcoming excessive friction. The problem with this method is that it causes periodontal alterations and undesired anchorage loss. [21] On the other hand, you can change the arch-wire's form and size or tweak the bracket's design to prevent friction. Coatings with nanoparticles are another option.

To minimise biofilm formation in orthodontics and make use of nanoparticles' antibacterial characteristics, two primary approaches exist:

- One method makes use of nanoparticles to cover the surfaces of the orthodontic brackets and wires. [22]
- Incorporating nanoparticles into resin and adhesive components is another method. Nanoparticle augmented composite material has several benefits, such as beautiful appearance, ease of handling, and very smooth surfaces. [19] Also, utilising nanofillers to smooth down orthodontic adhesive surfaces is a great way to cut down on bacterial adherence. [23]

### 7.1. Silver Nanoparticles (AgNPs) as a coating material

Research has shown that silver nanoparticles are the most efficient metal nanoparticle for inhibiting the development of Streptococcus mutans cells. A wide variety of microbes have been shown to be susceptible to its effects. Research has shown that orthodontic materials containing AgNPs can decrease the production of dental biofilms. This, in turn, means that enamel demineralisation is less likely to occur after fixed orthodontic mechanotherapy. [24,25]

### 7.2. Chitosan as a coating material

Chitosan is a naturally occuring polysaccharide obtained through the deacetylation of chitin. It is non-toxic, biodegradable, biocompatible, and exhibits antibacterial activity against Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, and Streptococcus mutans. [27,28]

Chitosan also exhibits antifungal properties. Histologically, chitosan inhibits microbial activity by inactivating bacterial enzymes, substituting lipopolysaccharides, forming teichoic acid by displacing metallic ions. Unlike chlorhexidine, chitosan has greater bioavailability due to low solubility and melting temperature.

### 7.3. Copper Oxide as a coating material

Yassaei et al. [29] reported no significant difference between the antibacterial effects of silver and copper oxide (CuO) nanoparticles, although the curing time was longer with CuO as compared to silver. Apart from that, copper is less expensive. The effect of both against Streptococcus mutans is similar [30]. Studies have confirmed that copper and copper-zinc nanoparticles significantly inhibits the microbial growth. [4] Research has shown that CuO particles incorporated into adhesives can reduce biofilm formation by 70 to 80% [31,32]. Furthermore, CuO nanoparticles also enhances the shear bond strength of adhesives by acting as nanofillers."

### 7.4. Nitrogen-incorporated Titanium Dioxide (N-Doped TiO2) coated brackets

Activation of N-doped TiO2 produces reactive free radicals such hydroxyl radicals (OH), superoxide ions ($O_2^-$), hydrogen peroxide ($H_2O_2$), and peroxyl radicals ($HO_2$). These radicals interact with lipids, enzymes, and proteins and possess antibacterial characteristics. Poosti et al. [33] brought to light-cure adhesives the possibility of adding $TiO_2$ nanoparticles, which might have antimicrobial properties. Adhesives that contain nitrogen-doped $TiO_2$ have an enhanced antibacterial effect without sacrificing the mechanical strength. [35,36] Salehi et al. [34] found that nitrogen-doped $TiO_2$ brackets show enhanced antimicrobial activity compared to standard stainless-steel brackets.

### 7.5. Zinc Oxide (ZnO) as a coating material

It has been reported that increased concentration of ZnO enhances antimicrobial activity but reduces shear bond strength. Notably, brackets coated with both ZnO and CuO nanoparticles exhibit better antimicrobial properties against Streptococcus mutans than those coated with CuO nanoparticles alone [37]. Studies by Kachoei et al. [38], Behroozian et al. [39], and Goto et al. [40] demonstrated that ZnO nanoparticle coatings significantly reduces the frictional forces between arch-wires and brackets resulting in reduced anchorage requirement thus lowering the risk of root resorption.

## 8. Orthodontic arch-wires and bracket materials

There is a wide range of orthodontic appliances that can be used in fixed orthodontic mechanotherapy. Materials including ceramics, polymers, titanium, and stainless steel are the most popular choices for brackets. Some common materials used to make arch-wires are stainless steel, nickel-titanium alloy, chrome-cobalt steel, and titanium-molybdenum alloy. The orthodontic bracket and arch-wire interact to produce friction, a crucial force that counteracts the pulling force by limiting the arch-wire's mobility inside the bracket.

Based on the kind of arch-wire and bracket used, saliva can either lubricate or adhere, making it the principal biological component impacting orthodontic friction. Thus, saliva can have an opposite effect on friction, making it either higher or lower. Research by Baker on the topic of saliva and friction revealed a 15–19% reduction in the frictional force [41]. Another important factor that causes more friction during treatment is dirt sticking to the surface of fixed appliances and archwires. Significant biofilm deposits were observed on orthodontic arch-wires after 8 weeks of use. Nanomaterials described to affect bacterial numbers can indirectly influence saliva condition and reduce plaque accumulation on orthodontic elements. Utilizing these nanomaterials could help to prevent increased frictional forces.

One approach in preventing plaque accumulation in orthodontic treatment is to incorporate nanoparticles with proven bacteriostatic effects. With its correct application, enhancement in the mechanotherapy by reducing the frictional coefficient at the bracket-archwire interface can be achieved.

**9. Silver, TiO2 nanoparticle incorporated orthodontic adhesives**

Various microorganisms, including gram-positive and gram-negative bacteria, fungi, protozoa, viruses, and antibiotic-resistant strains, have been shown to be susceptible to silver's antibacterial effects. [42] It is also found to be effective against Streptococcus mutans. [43] Candida stomatitis is a fungal infection that causes inflammation of the oral mucosa, which is marked by erythema, especially on the palatal mucosa. Silver nanoparticles have also been discovered to be beneficial in this case. Under orthodontic appliances, dentures, or retainers, it happens frequently. [45,46] The likelihood of establishing cariogenic flora in the mouth is increased when wearing acrylic resin braces because bacterial plaque is more likely to stick to them. [44] Without altering their physical characteristics, orthodontic adhesives that include silver nanoparticles considerably decrease the adherence of cariogenic Streptococci.

For removable orthodontic appliances like expanders, retainers, and functional appliances, cold-curing acrylic resins mainly composed of polymethyl methacrylate (PMMA) are enhanced with titanium dioxide (TiO2), silicon dioxide (SiO2), and silver nanoparticles.

**10. Future use of Nano-particles**

The field of orthodontics is poised to benefit greatly from the potential future applications of nanotechnology. These include shape-memory polymers, biomimetic adhesives, orthodontic nanobots that aid in tooth movement, and mini-implant anchorage screws (MIAs) that have been modified at the nanoscale to improve retention and facilitate easy removal after use. [47,48]

The class of materials known as shape memory polymers includes those that can change their form. When materials are exposed to heat or light, their physical characteristics change. One useful change is an increase in the modulus of elasticity. The therapy is more successful as a result. [49] Additionally, materials with self-repairing capabilities that can cure themselves have been created. Brackets and orthodontic arches made of these novel materials can include micro-ducts that hold dissolved medicinal medicines. The nanobubbles rupture when a wire or bracket breaks, allowing the monomer to fill the space with medicinal substances. [50]

By using the development of localised Van der Waals forces, biomimetic adhesives offer a bonding process that is gentler on enamel and compatible with orthodontic gear. [51] It provides strong, reversible adhesion. [52] This technique eliminates the need for prior enamel conditioning without hampering the bond strength. Materials that are coated with titanium oxide nanoparticles or other self-cleaning agents create a passive layer on the surface that keeps contaminants at bay. There is a lot of curiosity about photocatalysis, which occurs when light interacts with titanium oxide. [53] Methods for inducing this reaction on Ni-Ti arch-wires are currently under investigation. The surface of these materials may be made to have a crystalline rutile (titanium dioxide) structure by depositing a layer of titanium oxide using electrolytic treatment and heat. [54]

**11. Conclusions**

Nanotechnology has become increasingly significant in dentistry, with a lot of potential for substantial innovations and their productive utility, particularly in orthodontics. Positive results have spurred further research into areas such as orthodontic adhesives, coating of brackets and wires resulting in enhanced antimicrobial properties. This review highlights the effect of nanoparticles and with it the increased efficiency of orthodontic treatment.

The mechanical and bactericidal characteristics of nanomaterials have found a use in orthodontics, as

demonstrated in this paper. [22] You can avoid the demineralisation of enamel after fixed orthodontic treatment by adding them to acrylic resins, cements, and adhesives.
Nanomaterial coating have effectively reduced friction between the arch-wire and bracket, thus improving the outcome of orthodontic treatment.
Biocompatibility and cytotoxicity are critical factors to consider when introducing new bioactive materials. Existing literature on application of nanomaterials in orthodontics offers limited insight into their potential adverse effects. Although nanomaterials offer undeniable advantages, our understanding of them still remains incomplete. Hence, it is imperative to validate and meticulously assess their properties, ensuring that potential benefits align with associated risks.
The utilization of nanomaterials, particularly in orthodontics, is being researched for further expansion. The integration of nanotechnology holds significant promise for the future of orthodontics.

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