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Review Article

Nanotechnology in Orthodontics: Current Applications and Future Perspectives

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ABSTRACT

Dentistry is one of the professions that use nanoparticles. However, there are concerns regarding their unidentified effects on human health and the environment. This study aimed to investigate the extent of the use of nanoparticles in orthodontics because of their growing use in other dental specialties. This review article uses the keywords nano chitosan, nano zinc oxide, nano silver, nano curcumin, nanoparticles, and orthodontics. The relevant publications were chosen after searching the Google Scholar, Scopus, PubMed, and Web of Science databases using the requested keywords. The investigations indicate that tetravalent ammonium derivatives, titanium oxide, curcumin, zinc oxide, chitosan, and all silver nanoparticles have strong antibacterial qualities. Further research is recommended on the effects of each of these nanoparticles on binding strength. There is inadequate data to support the use of ACP nanoparticles, calcium-phosphate nanoparticles, and fluoride to decrease caries; hence, further research is recommended for further exploration. According to studies, adding zinc oxide nanoparticles to orthodontic wires reduces friction between the wire and the bracket, whereas adding titanium oxide nanoparticles to the bracket increases friction. Despite the research on the subject of nanoparticle toxicity being sparse, it appears that nanoparticles are not more harmful than ordinary chemicals.

Keywords: Dentistry, Nanotechnology, Nanoparticles, Orthodontics

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Introduction

Nano is taken from a Greek term that means little. Nano is a billionth of a unit. This quantity of mass is roughly equivalent to two to three atoms [1, 2]. Nanomaterials are solids that are less than 100 nm in at least one dimension, such as nanometer clusters, films, and plates having a thickness of less than 100 nm [3, 4].

Because of their tiny size, nanomaterials exhibit unique properties. Nanomaterials, for instance, are lighter and stronger than other materials, with distinct mechanical and chemical characteristics [5]. Materials with nanoscale size have a high surface-to-volume ratio and hence react better with other materials. For instance, these chemicals react with cell membranes and bacteria and exhibit their antimicrobial capabilities on a large scale [6, 7].

It has been demonstrated that nanoparticles have superior physical, chemical, mechanical, and optical characteristics than microparticles and may be utilized to create dental materials with excellent mechanical properties and greater antibacterial effects [4]. The introduction of nanoparticles into the area of dentistry has generated tremendous development in this sector, including the prevention of cavities, improvement of antibacterial properties of materials, improvement of mechanical characteristics of materials, and so on [5].

There are two production techniques in nanotechnology [8, 9]. Bottom-up technique, in which atoms are stacked side by side to achieve the necessary nanoscale size. Today, this strategy is widely employed. Another way is the top-down approach, which involves hammering, grinding, and chemical corrosion of crushed materials to produce nano-sized particles. These technologies are more restricted, and controlling them is more complex and cannot be applied to all materials. Because of their unique qualities, nanoparticles are employed in a variety of industries, including dentistry. However, there are worries about the unknown impacts on the environment and human health [10-12]. The goal of the present research was to examine the utilization of nanoparticles in orthodontics because of their growing usage in many dental specialties.

Materials and Methods

The present study was conducted as a review of the evidence available in electronic databases. The present study is a review study and was conducted using the keywords Nano Chitosan, Nano ZnO, Nano silver, Nano crucumin, Nanoparticles, and Orthodontics. The desired keywords were searched in Google Scholar, Scopus, PubMed, and Web of Science databases, and the relevant articles were selected.

The search range of articles was from 2010 onwards. After searching with the mentioned keywords and reviewing each of these articles, the articles that used nanoparticles in orthodontic appliances were reviewed. After the review, the articles were divided based on the different applications of nanoparticles.

Results and Discussion

Application of nanoparticles to investigate its antibacterial effects

Silver

More research has been conducted on silver nanoparticles' antibacterial qualities than on any other type of nanoparticle. The use of silver nanoparticles in orthodontic materials and devices is given particular consideration because of their antimicrobial qualities. These nanoparticles are employed in acrylic, mouthwash, orthodontic wires, and orthodontic elastomers in addition to primers. The impact of adding 1% silver and 1% zinc oxide nanoparticles to orthodontic composite on *Streptococcus mutans* and *Lactobacillus* was assessed by Kasraei *et al*. [13]. The study's findings demonstrated the strong antibacterial properties of zinc oxide and silver nanoparticles. In comparison to silver, zinc oxide had a stronger antibacterial impact on *Streptococcus mutans*. However, Lactobacillus was the same.

Silver's strong antibacterial qualities are supported by several further research [14–17]. Silver nanoparticles utilized in orthodontics have established and confirmed antibacterial qualities.

According to a study, the development of *Streptococcus mutans*, *Staphylococcus aureus*, and *Escherichia coli* bacteria is inhibited by the elastomer containing silver nanoparticles when compared to the standard elastomer. Additionally, as compared to the control group, an improvement in its physical attributes was noted [18].

Research on the use of silver nanoparticles in orthodontic bands has shown that a consistent and long-lasting layer of these nanoparticles could be formed on the band's exterior. These nanoparticles produce silver nanoparticles regularly and exhibit strong antibacterial characteristics when applied to the bandage's surface [19–21]. Even while these antibacterial qualities could wane with time [19].

In one study, Mhaske *et al*. [22] looked at how nickel-titanium wires coated with silver nanoparticles and stainless steel affected the Lactobacillus acidophilus microbes' ability to adhere and fight off germs. Wires made of stainless steel and nickel-titanium, which were not coated with silver nanoparticles, increased in weight by 35.4% and 20.5%, respectively, as a result of bacteria and detritus adhering to them. It was 4.08% for stainless steel wires and 4.4% for nickel-titanium wires when silver nanoparticles were used. Compared to coated wires, this weight gain was negligible for uncoated wires. The coated wires considerably reduced the Lactobacillus acidophilus bacteria's survival rate.

In addition to inhibiting *Streptococcus mutans*, covering orthodontic brackets with silver nanoparticles has been shown to have this impact both near and far from the bracket [23, 24]. Thus, caries on smooth surfaces can be decreased by applying silver nanoparticles to orthodontic brackets [23].

According to research, patients who wear separate retainers containing silver nanoparticles had a decreased incidence of *Streptococcus mutans*. Strong impacts over *Streptococcus mutans* were seen in the group that used mobile ionizers containing silver nanoparticles, and the quantity of this bacteria was significantly decreased. Despite this, the planktonic control of bacteria is more affected by these nanoparticles [24–26]. Venugopal *et al*. [27] looked at how the antibacterial qualities of orthodontic microimplants were affected when their surface was coated with titanium and silver nanoparticles. The findings of this investigation showed that, after 24 hours, micro-implants coated with AgNP-coated biopolymer (Ti-BP-AgNP) had an inhibitory impact on bacterial growth. Due to its superior antibacterial qualities, AgNP-coated biopolymer (Ti-BP-AgNP) will be a potential implantable biomaterial, even though micro-implants coated with regular AgNPs (Ti-ANP) did not have an inhibitory impact on the development of bacteria.

Curcumin

Curcumin's capacity to break down the peptidoglycan wall of bacteria is what gives it its antibacterial properties. Numerous bacteria, including *Streptococcus*, *Lactobacillus*, and *Staphylococcus*, are inhibited in their development and proliferation by this chemical, according to earlier research [28]. The impact of adding 1.5 and 10% by weight of curcumin nanoparticles on the composite's bond strength and antibacterial qualities was examined by Sodagar *et al*. [4]. According to the research's findings, adding all three concentrations considerably lowers the levels of *Streptococcus mutans*, *Streptococcus sanguis*, and *Lactobacillus acidophilus*; nevertheless, a concentration of 1% by weight is advised to obtain the strongest band.

Chitosan

Strong antibacterial qualities have been demonstrated by the usage of chitosan nanoparticles in adhesives. The antibacterial properties of chitosan are enhanced by raising its concentration. Because the planktonic form of bacteria is less cohesive and disintegrates more easily than the biofilm, this nanoparticle has a stronger influence on it. A 10% concentration was shown to have the strongest antibacterial impact in one investigation [29]. When it comes to caries microorganisms, chitosan nanoparticles have more potent antibacterial properties than chitosan particles. Around chitosan nanoparticles, the halo of the absence of growth in the culture media is greater [30]. These nanoparticles' tiny size and increased interaction with bacteria are what give them their antibacterial properties. When chitosan nanoparticles are added at a concentration of 5 mg/ml, *Streptococcus mutans* biofilm production is reduced by 93.4% [30]. Good antibacterial and anti-caries capabilities have also been demonstrated when chitosan nanoparticles are added to mouthwash [31]. In contrast to two commercial mouthwash types that contain chlorhexidine and essential oil ingredients, the results of a study demonstrated that the mouthwash containing chitosan nanoparticles had better antibacterial qualities and could handle the development of biofilm and its maturation by adhering to the microorganisms [31].

Titanium oxide

Because of their photocatalytic qualities, TiO_2 nanoparticles exhibit antibacterial activity that is triggered via UV light. Following exposure to UV light, free radicals are created, which interact with the biomolecules of microorganisms. The photocatalytic property is restricted to ultraviolet light, which includes light with a wavelength of less than 387 nm. Only 5% of the spectrum of white light is made up of UV radiation. However, UV radiation poses a risk of harming the skin and eyes itself [32].

In the region of intense visible light, doping and surface modification of TiO_2 nanoparticles can activate their antibacterial properties. It has been demonstrated that N-doping is the best technique for using both visible and ultraviolet light to activate titanium oxide nanoparticles. According to a study, compared to traditional brackets, the surface of orthodontic brackets coated with a thin coating of N-doped TiO_2-xy attracts fewer germs. Consequently, it is advised to apply N-doped TiO_2-xy to the brackets to stop gingivitis and enamel demineralization [32]. Additionally, it has been demonstrated that titanium oxide nanoparticles efficiently lower the number of bacteria in brackets coated with them [24].

In addition, titanium nanoparticles have been included in the glass ionomer. The study's findings show that the antibacterial qualities and bond strength of the GI base liner remain unchanged when titanium nanoparticles are added. Without weakening the connection, restorative enhances antibacterial qualities [33].

Ahrari *et al*. [34] tested mouthwashes containing various nanoparticles for their ability to inhibit *Streptococcus mutans* and *Streptococcus sanguis*. They tested mouthwashes with TiO_2, CuO, ZnO, and Ag nanoparticles to sodium fluoride and parahexidine. The study's findings revealed that sodium fluoride mouthwash has no antibacterial activity against these two pathogens. According to the conclusions of this study, the mouthwash with titanium oxide nanoparticles is the best in terms of antibacterial activity against *Streptococcus mutans* and *Streptococcus satgulis*.

According to an analysis of the staining impacts of mouthwashes including ZnO, Ag, Cu, TiO_2, chlorhexidine, and water nanoparticles, mouthwash containing zinc oxide nanoparticles causes the greatest tooth discoloration, while mouthwash containing titanium oxide nanoparticles causes the least. Comparing these mouthwashes to chlorhexidine, the amount of discoloration caused was equal to or greater than that of titanium oxide. Brushing won't be able to get rid of discoloration. According to the research's outcomes, these nanoparticles in this form are not suitable for replacing chlorhexidine to eliminate its adverse impacts [35].

In some treatments and throughout the retention phase, the use of detachable orthodontic plates is crucial. Antibacterial qualities are essential in this equipment since they must be used over time and interfere with saliva's natural ability to cleanse teeth. Silicone and titanium oxide nanoparticles were added to polymethyl mena acrylate by Sodagar *et al*. [36], who then examined the impact on dental caries bacteria. The study's findings show that the addition of nanoparticles in acrylic composition may lower the bacterial population from 3.2-99%. The kind of bacteria being studied, the type of nanoparticles, and the ambient light all affect this impact. The results of this investigation validate the potent antimicrobial capabilities of these two nanoparticles in acrylic.

Polyethyleneimine nanoparticles

This material is an ammonium derivative that is tetravalent. Cross-linked quaternary ammonium (polyethyleneimine) nanoparticles (QPEI) were used in mobile plaque resin, which demonstrated that when used at low concentrations, these nanoparticles have strong antibacterial activity in the in vivo environment and inhibit a variety of salivary microbes [37].

CuO and ZnO

Despite this, silver nanoparticles' antibacterial qualities have been demonstrated. Nevertheless, the danger of tooth discoloration (pigmentation) and the biological safety of silver nanoparticles make their practical application challenging. Thus, it is especially crucial to employ nanoparticles with few issues and drawbacks [38].

Ramazanzadeh *et al*. [39] studied the antibacterial impacts of coating orthodontic brackets with zinc oxide and CuO nanoparticles and determined that in the short term, the antibacterial capabilities of the ZnO-CuO and CuO combination against *Streptococcus mutans* are positive. According to the results of this research, zinc oxide nanoparticles alone are less suggested than ZnO-CuO and CuO.

Application of nanoparticles to investigate their effect on the bond strength of orthodontic bracket with tooth surface

In orthodontics, the bonding technique using composite resin is mostly utilized to join the bracket to the surface of the tooth. The accumulation of plaque, the development of white lesions, and the breaking of the band are some of the drawbacks of bonding, despite its benefits, which include excellent aesthetics and ease of use. These flaws result in longer treatment times, longer clinical work periods, and higher treatment costs. Numerous techniques have been developed to stop tooth decay and biofilm growth. Adding antibacterial materials to the composite resin is one technique. Fluoride and chlorhexidine are the two materials utilized for this. It is thought that because of their tiny size, nanoparticles have strong antibacterial qualities [40]. Understanding how nanoparticles affect the binding strength between the bracket and composite or cement of orthodontic braces is crucial, in addition to their antibacterial properties.

Silver nanoparticles

Because of its antibacterial qualities, silver has garnered a lot of interest in nano-dentistry. Although the antibacterial qualities of silver nanoparticles make them advantageous, their impact on bond strength has been questioned when added to orthodontic glue. According to earlier research, the bond strength may be decreased by adding silver nanoparticles to the adhesive; brackets glued with composites containing silver nanoparticles have a statistically significant reduced bond strength [41]. According to Degrazia *et al*. [42], this band strength drop is therapeutically acceptable while being statistically significant. Silver nanoparticles were added to reinforced glass ionomer cement in another investigation, and it was shown that while the bond strength is still satisfactory, it diminishes as the number of silver nanoparticles increases [19].

Blocher demonstrated, however, that there is no discernible difference in bond strength between brackets joined with normal resin composite and resin composite containing silver nanoparticles [43]. The impact of incorporating nano-hydroxyapatite and silver nanoparticles on the strength of orthodontic adhesive bonding was examined by Akhavan *et al*. [44]. According to their findings, the bond strength is increased when silver hydroxyapatite nanoparticles are added at rates of 1 and 5% by weight, but it is decreased when nanoparticles are added at rates of 10% by weight. Two investigations have shown that while adding silver nanoparticles to orthodontic band cement may somewhat weaken the band, the strength of the band is still clinically acceptable. Other mechanical characteristics that are comparable include modulus and ultimate transverse strength [45].

Titanium oxide

The photocatalytic characteristics of this particle have received a lot of interest in the last several decades. According to studies, this Nano Valley has antibacterial qualities and can improve the mechanical qualities of adhesives when added. The bond strength is also on par with or greater than that of the study's control group [41].

Research on using this nanoparticle in orthodontic adhesives has shown mixed findings. Two sets of brackets bonded with an adhesive containing titanium oxide nanoparticles and a normal adhesive did not significantly differ in bond strength or ARI index, according to Felemban *et al*. [46]. The lowest binding strength was found in brackets glued with an adhesive containing titanium oxide nanoparticles, according to research by Reddy *et al*. [41]. A further investigation on the impact of including titanium oxide and zinc oxide nanoparticles into Transbond XT glue revealed that the adhesive containing these tiny particles had increased tensile, bond, and compressive strengths [46].

According to the findings of a study on the addition of these nanoparticles to the ionomer class, the bond strength remains unchanged when titanium particles are tattooed onto glass ionomer luting, base, and repair [33].

Sepiolite

A substance called sepiolite, which has a needle-like crystal structure, is created when phyllosilicate binds together. Using this material as a nanofiller is one of its novel applications. Because of the active regions on its surface, this material interacts with both nanofiller and nanofiller-matrix. The produced polymer is further strengthened by this nanoparticle because of its exceptional adherence and matrix compatibility as well as its special qualities. Investigations were conducted on the impact of incorporating nano sepiolite particles into dentin bond materials. According to the results, this nanoparticle strengthens the bond between dentin and dentine; the bond strength increases as the concentration of the nanoparticle increases. The highest concentration examined, 1%, produced the greatest increase in bond strength [47]. Research on the use of this nanoparticle in orthodontics has not yet been conducted.

Curcumin

This compound is derived from the turmeric plant and is used as a herbal remedy to heal illnesses in addition to being used as a spice. Many bacteria, including Lactobacillus and Staphylococcus, are inhibited in their development by this chemical. While curcumin's insolubility is seen as a significant drawback, the work by Sodagar *et al*. [4] suggests adding 1% by weight of curcumin nanoparticles to orthodontic composite with good antibacterial benefits and no detrimental effects on bond strength.

Chitosan

Fungi and some plants contain chitosan nanoparticles, which are a biopolymer that is produced by distilling quinine. Owing to its antiviral, antifungal, and antimicrobial qualities, this material finds application in a variety of industries, including the food, pharmaceutical, cosmetic, and dental sectors [48]. Research by Sodagar *et al*. [48] on the addition of chitosan nanoparticles to orthodontic adhesives found that all concentrations of the substance exhibited antibacterial qualities against *Streptococcus mutans* and *Streptococcus sangulis*. The binding strength of brackets bonded with a composite of chitosan nanoparticles and the control group did not differ statistically significantly. Therefore, even if this nanoparticle has antibacterial qualities, its application won't have a big impact on the bond's strength.

Zinc oxide

Compared to brackets glued with traditional composite, brackets bonded with an adhesive containing this nanoparticle have a much reduced binding strength [41].

Application of nanoparticles to prevent caries

Compared to brackets glued with traditional composite, brackets bonded with an adhesive containing this nanoparticle have a much reduced binding strength. Dental caries around orthodontic brackets is a serious clinical issue. There are now several techniques to stop tooth decay and biofilm growth. Incorporating antibacterial materials into the composite resin is one approach. Fluoride and chlorhexidine are the two materials utilized for this [48]. Nanofilled composites that release fluoride have been demonstrated to release fluoride just as much as micro-filled composites that release fluoride. Thus, adding fluoride-releasing nanofield particles to the composite in an attempt to lower dental cavities is not advised [49].

ACP is one of the components that may be added to the composite that can release calcium and phosphate, which is another method of reducing deterioration. ACP's inadequate mechanical qualities are its biggest drawback. The mechanical qualities of ACP nanoparticles can be twice as strong as those of ACP microparticles while releasing phosphate and calcium. Prior research has demonstrated that the mineral content and *Streptococcus mutans* count are both greater in the ACP-NPS adhesive group up to six months following bracket bonding. Thus, it is advised to utilize ACP-MPS adhesive. Additionally, a charged cement that contains amorphous calcium and phosphate nanoparticles can release calcium and phosphate continually. The components of refillable cement are ethoxylated bisphenol dimethacrylate (EBPADMA) and glycerol dimethacrylate (PMGDM). The binding strength between the new (uncharged) cement and traditional orthodontic cement is equal. $CaCl_2$ and K_2HPO_4 are the ingredients of the calcium and phosphate charging solution. When this cement is submerged in the charging solution three times a day for one minute, it can release calcium and phosphate for fourteen days [50].

Under orthodontic braces, microleakage may contribute to dental cavities. It has been demonstrated that adding nano-hydroxyapatite to glass ionomer cement may greatly lower microleakage [51].

Application of nanoparticles to reduce friction between wire and bracket

Force is needed to accomplish the aim, get beyond the resistance caused by contact with the bracket, and induce the bone remodeling needed for tooth movement as the teeth glide down the archwire. The anchoring unit's teeth regrettably experience the reaction of both forces, namely the force of teeth movement and the resistance to friction. Research has indicated that in optimal circumstances, the frictional force is high. For instance, if a canine tooth needs to be moved to close the gap left by its extraction, 100 grams of force will be needed to move the tooth and another 100 grams to overcome frictional resistance. This means that the total force needed to move the tooth is twice as much as we would anticipate [52].

Zinc oxide

When 0.016-inch steel wire is covered with nano zinc oxide particles, the friction during sliding in the metal bracket is reduced by 39%. In ceramic brackets, applying zinc oxide nanoparticle coating on orthodontic wires also lessens sliding resistance. Such an impact has not been observed when orthodontic wire and brackets or zinc oxide nanoparticles are coated simultaneously [53].

Titanium oxide nanoparticles and silver nanoparticles

Nanoparticles of titanium oxide are not advised for bracket coating since they greatly increase the friction between the wire and the stainless steel bracket. There is conflicting evidence about the use of silver nanoparticles to coat steel brackets since they also marginally enhance friction [24].

Application of nanoparticles to investigate the physical properties of acrylic

The use of nanoparticles in acrylic has received a lot of interest lately. These substances make up the majority of moving plates. In addition to researching the antibacterial qualities, it's critical to understand how these nanoparticles affect the physical characteristics of acrylic.

Silver

Studies on the addition of silver nanoparticles to acrylic have produced conflicting findings. It has been demonstrated that these nanoparticles improve Selecta Plus acrylic's flexural strength; nevertheless, additional additions once again result in a drop in flexural strength. The converse of this happens with fast acrylic; that is, when nanoparticles are added, the bending strength first drops before rising back to its starting point. As a result, the kind of grill and the proportion of silver nanoparticles added to determine how adding them affects the bending strength of acrylic [54].

Tio2 and Sio2

The addition of titanium oxide or silicon oxide nanoparticles to acrylic diminishes bending strength, and this loss is proportional to the nanoparticle dosage.

Flexural strength does not change much between acrylic-containing titanium oxide nanoparticles and silicon oxide nanoparticles. Although acrylic with titanium oxide demonstrates less strength than silicon oxide [36].

Application of nanoparticles to make orthodontic adhesive visible (Visibility)

The brackets and any leftover glue must be taken out once the orthodontic therapy is complete. However, it might be challenging to remove the orthodontic glue since it is the same color as the tooth. There is a chance that the enamel might be harmed when using rotary tools to remove glue [55]. After deboning the brackets using ultraviolet or near-ultraviolet light irradiation, the residual composite can be characterized by adding europium particles to a network of zinc oxide nanoparticles [56].

Conclusion

The investigations indicate that all silver nanoparticles, as well as derivatives of tetravalent ammonium, titanium oxide, chitosan, curcumin, and zinc oxide, have strong antibacterial qualities. The addition of silver nanoparticles to orthodontic composite weakens the binding. To ascertain the clinical suitability of the bond strength of brackets bonded with composites containing silver nanoparticles, additional research is necessary. Sepiolite nanoparticles appear to strengthen bonds, while curcumin and chitosan nanoparticles appear to not affect binding strength. The findings of titanium oxide nanoparticles' binding strength are incongruous. To further understand the impact of each of these high-band strength nanoparticles, more research is advised. Fluoride nanoparticles did not have a beneficial impact in lowering caries, even though adding ACP nanoparticles and a charged cement of calcium phosphate nanoparticles to the composite produced a regular release of calcium and phosphorus ions. As a result, fresh research is advised for more analysis. According to studies, the friction between orthodontic wires and brackets is decreased when zinc oxide nanoparticles are added. However, the friction is increased when titanium oxide nanoparticles are added to the bracket. Other nanoparticles have not yet been studied. There is not enough research or conclusive findings on the examination of how nanoparticles affect the physical characteristics of acrylic. The toxicity of nanoparticles is one of the key considerations in their utilization. It would appear that nanoparticles are at least not more harmful than ordinary chemicals, notwithstanding the paucity of information in this area. More research is advised to elucidate these aspects because of the broad scope of the field of nanotechnology and the paucity of research on the impact of nanoparticles on the physical characteristics of orthodontic acrylics, the strength of orthodontic adhesive bonds, fluoride release, and their impact on wire and bracket friction.

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