Review Article

STUDYING THE APPLICATION OF NANOPARTICLES IN ORTHODONTICS: A REVIEW STUDY

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ABSTRACT

Nanoparticles are used in various fields such as dentistry. Although there are concerns about their unknown effects on the environment and human health. Due to the increasing use of nanoparticles in various fields of dentistry, the purpose of this study was to review the application of nanoparticles in orthodontics. 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. According to the studies, all silver nanoparticles, titanium oxide, curcumin, zinc oxide, chitosan, and tetravalent ammonium derivatives show good antibacterial properties. To investigate the effect of each of these nanoparticles on bond strength, more studies are recommended. Regarding the addition of ACP nanoparticles, calcium-phosphate nanoparticles, and fluoride to reduce caries, the current evidence is insufficient, so new studies are recommended for further investigation. Studies show that adding zinc oxide nanoparticles to orthodontic wires reduces the friction between the wire and the bracket while adding titanium oxide nanoparticles to the bracket increases the friction. Although the evidence in the field of toxicity of nanoparticles is insufficient, it seems that nanoparticles are at least not more toxic than conventional substances.

Key words: Dentistry, Nanotechnology, Nanoparticles, Orthodontics.

Introduction

The word Nano is derived from a Greek word meaning small. A Nano is one-billionth of a unit. This amount of matter is approximately equal to 2 to 3 atoms [1, 2]. Nanomaterials are substances that are less than 100 nm in at least one dimension, which include nanometer clusters and films and plates with a thickness of less than 100 nm [3, 4].

The small size of Nanomaterials has made these materials have different characteristics. For example, Nanomaterials are lighter and stronger and have different mechanical and chemical properties [5]. Materials in Nano dimensions have a high surface-to-volume ratio and therefore have better reactions with other materials. For example, these substances react with cell membranes and microbes and exert antimicrobial properties on a wide scale [6, 7].

It has been shown that nanoparticles have superior physical, chemical, mechanical, and optical properties compared to microparticles and can be used to make dental materials with high mechanical properties and better antimicrobial effects [4]. The introduction of Nanoparticles into the field of dentistry has caused significant progress in this field, which includes the prevention of caries, improvement of antimicrobial properties of materials, improvement of mechanical properties of materials, etc. [5].

There are two manufacturing approaches in nanotechnology [8, 9]: Bottom-up approach, in which atoms are arranged side by side to reach the desired size in Nano size. Today, this method is mostly used. Another method is the Top-down Approach, which uses methods such as hammering, grinding, and chemical corrosion of crushed materials to reach Nano-sized particles. These methods are more limited and control over them is more difficult and cannot be done on all materials. Due to their different properties, nanoparticles are used in various fields such as dentistry. Although there are concerns about their unknown effects on the environment and human health [10-12]. Due to the increasing use of nanoparticles in various fields of dentistry, the purpose of this study was to review the application of nanoparticles in orthodontics.

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

Studies on the antibacterial properties of silver nanoparticles have been done more than other nanoparticles. Due to the antibacterial properties of silver nanoparticles, there is special attention to adding them to orthodontic devices and materials. In addition to primer, these nanoparticles are used in orthodontic elastomers, orthodontic wires, mouthwash, and acrylic. Kasraei *et al*. [13] evaluated the effect of adding 1% silver particles and 1% zinc oxide nanoparticles to orthodontic composite on *Streptococcus mutans* and *Lactobacillus*. The results of this study showed that silver and zinc oxide nanoparticles have high antibacterial effects. The antibacterial effect of zinc oxide against *Streptococcus mutans* was greater than that of silver. But there was no difference in *Lactobacillus*.

Several other studies confirm the significant antimicrobial properties of silver [14-17]. The antimicrobial properties of silver nanoparticles used in orthodontics are proven and definite.

A study showed that the elastomer containing silver nanoparticles has an inhibitory effect on the growth of *Streptococcus mutans*, *Staphylococcus aureus*, and *Escherichia coli* microorganisms compared to the usual elastomer. In addition, an improvement was also observed in its physical characteristics compared to the control group [18].

Studies on the use of silver nanoparticles in orthodontic bands showed that it is possible to create a uniform and stable coating of these nanoparticles on the surface of the band. The surface coating of the bandage with these nanoparticles has favorable biocompatibility regularly releases silver nanoparticles and shows good antimicrobial properties [19-21]. Although these antimicrobial properties may decrease over time [19].

In a study, Mhaske *et al*. [22] investigated the antibacterial and anti-adhesion effects of stainless steel and nickel-titanium wires coated with silver nanoparticles on *Lactobacillus acidophilus* microorganism. In the group of wires without silver nanoparticles coating, stainless steel, and nickel-titanium wires had 35.4% and 20.5% increase in weight due to the adhesion of debris and bacteria, while this increase in weight was for coated wires. With silver nanoparticles, it was 4.08% for stainless steel wires and 4.4% for nickel-titanium wires. This increase in weight was significant for uncoated wires and insignificant for coated wires. The coated wires significantly decreased the survival rate of Lactobacillus acidophilus bacteria. Covering orthodontic brackets with silver nanoparticles also inhibits *Streptococcus mutans* [23, 24] and this inhibitory effect is seen not only around the bracket but also at a distance away from the bracket. Therefore, covering orthodontic brackets with silver nanoparticles can reduce caries on smooth surfaces [23].

Studies have shown that the rate of *Streptococcus mutans* is lower in patients who use removable retainers with silver nanoparticles. In the group with mobile ionizers containing silver nanoparticles, strong effects against *Streptococcus mutans* were seen and the amount of this microorganism was greatly reduced. Although these nanoparticles have a greater effect on the planktonic control of bacteria [24-26]. Venugopal *et al*. [27] investigated the effect of covering the surface of orthodontic microimplants with silver and titanium nanoparticles on their antimicrobial properties. The results of this study showed that after 24 hours, the inhibitory effect on the growth of bacteria can be seen around micro-implants covered with AgNP-coated biopolymer (Ti-BP-AgNP). While micro-implants covered with Regular AgNPs (Ti-ANP) did not show an inhibitory effect on the growth of bacteria, so AgNP-coated biopolymer (Ti-BP-AgNP) will be a promising implantable biomaterial due to its excellent antibacterial properties.

Curcumin

The antibacterial activity of curcumin is due to its ability to destroy the peptidoglycan wall of bacteria. Previous studies have shown that this substance inhibits the growth and proliferation of many bacteria such as *staphylococcus*, *lactobacillus*, and *streptococcus* [28]. Sodagar *et al*. [4] investigated the effect of adding 1.5 and 10% by weight of curcumin nanoparticles on the bond strength and antibacterial properties of the composite. The results of this study showed that the addition of all three concentrations significantly reduces *Streptococcus mutans*, *Streptococcus sanguis*, and *Lactobacillus acidophilus*, but to achieve the greatest band strength, a concentration of 1% by weight is suggested.

Chitosan

The use of chitosan nanoparticles in adhesives has shown strong antibacterial properties. By increasing the concentration of chitosan, the antimicrobial properties increase. This nanoparticle has a greater effect on the planktonic form of bacteria than the biofilm, which is due to the disintegration and less cohesion of the planktonic form. In a study, its maximum antibacterial effect was obtained with a concentration of 10% [29]. Chitosan nanoparticles have stronger antibacterial effects against caries microorganisms than chitosan particles. The halo of lack of growth in the culture medium around chitosan nanoparticles is larger [30]. The reason for the antibacterial effect of these nanoparticles is the small size and higher reactivity of these particles or bacteria. Chitosan nanoparticles at a concentration of 5 mg/ml reduce the formation of *Streptococcus mutans* biofilm by 93.4% [30]. Adding chitosan nanoparticles to mouthwash has also shown good antibacterial and anti-caries properties [31]. The findings of a study showed that the mouthwash containing chitosan nanoparticles, compared to two commercial types of mouthwash with chlorhexidine and essential oil elements, was able to cope with the formation of biofilm and its maturation by sticking to the microorganisms, and had more favorable antibacterial properties than show these two types of mouthwash [31].

Titanium oxide

Tio2 nanoparticles have photocatalytic properties, that is, the antibacterial activity of this substance is stimulated by ultraviolet light radiation. After UV light irradiation, free radicals are produced that react with the biomolecules of microbes. The photocatalytic property is limited to the wavelength range of ultraviolet light, which includes a wavelength of less than 387 nm. The range of ultraviolet light is only 5% of the spectrum of white light. On the other hand, there is a possibility of damage to the eyes and skin during ultraviolet radiation [32].

Doping and changing the surface of Tio2 nanoparticles can cause the antibacterial property to be activated in the range of sharp visible light. It has been shown that N-doping is an ideal method for the activation of titanium oxide nanoparticles with both visible and ultraviolet light. A study has shown that the surface of orthodontic brackets covered with a thin layer of N-doped Tio2-xy attracts fewer microorganisms compared to conventional brackets. Therefore, coating the brackets with N-doped Tio2-xy is recommended to prevent enamel demineralization and gingivitis [32]. It has also been proven that titanium oxide nanoparticles effectively reduce bacteria in brackets covered with these nanoparticles [24].

Titanium nanoparticles have also been added to the glass ionomer. The results of a study showed that adding titanium nanoparticles to GI base liner does not change the antimicrobial properties and bond strength while adding titanium nanoparticles to GI Restorative improves antimicrobial properties without reducing bond strength [33].

Ahrari *et al*. [34] evaluated mouthwashes containing different nanoparticles against Streptococcus mutans and Streptococcus sangulis. They compared mouthwashes containing Tio2 CuO ZnO and Ag nanoparticles with sodium fluoride and parahexidine. The results of this study showed that sodium fluoride mouthwash has no antibacterial effect against these two microorganisms. Based on the findings of this study, the best mouthwash in terms of antimicrobial activity against *Streptococcus mutans* and *Streptococcus satgulis* is the mouthwash containing titanium oxide nanoparticles.

Examining the staining effects of mouthwashes containing nanoparticles of ZnO, Ag, Cu, TiO2, chlorhexidine, and water showed that the most tooth discoloration is related to mouthwash containing zinc oxide nanoparticles and the least tooth discoloration is related to titanium oxide mouthwash. These mouthwashes produced as much or even more discoloration (even titanium oxide) compared to chlorhexidine. After discoloration, brushing cannot remove the color. The findings of this study showed that these nanoparticles in this form cannot be used as a substitute for chlorhexidine in removing its side effects [35].

The use of removable orthodontic plates during some treatments and in the retention period is of considerable importance. Due to the need to use these devices over time and their interference with the natural washing of teeth by saliva, it is important to have antibacterial properties in these appliances. Sodagar *et al*. [36] inserted titanium oxide nanoparticles and silica nanoparticles into polymethyl mena acrylate and investigated its effect on caries bacteria. The results of this study showed that nanoparticles used in acrylic composition can reduce the number of bacteria from 3.2 to 99%. This effect depends on the type of nanoparticles, ambient light, and the type of bacteria under investigation. The findings of this study confirm the strong antibacterial properties of these two nanoparticles in acrylic.

Polyethyleneimine nanoparticles

This substance is a tetravalent ammonium derivative. The use of cross-linked quaternary ammonium (polyethyleneimine) nanoparticles (QPEI) in mobile plaque resin showed that the use of these nanoparticles in a low concentration causes significant antibacterial activity in the in vivo environment, and inhibits a wide range of salivary microorganisms [37].

CuO and ZnO

Although the antimicrobial properties of silver nanoparticles have been proven. However, the biological safety of silver nanoparticles as well as the risk of tooth discoloration (pigmentation) make their clinical use difficult. Therefore, the use of nanoparticles with minimal complications and problems is of particular importance [38].

Ramazanzadeh *et al*. [39] investigated the antibacterial effects of coating orthodontic brackets or zinc oxide and Cuo nanoparticles and concluded that in the short term, the antibacterial properties of Zno-Cuo and Cuo mixture against *Streptococcus mutans* are favorable. Based on the findings of this study, zinc oxide nanoparticles alone are less recommended than ZnO-CuO and CuO.

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

The bonding method with composite resin in orthodontics is mainly used to connect the bracket to the tooth surface. Unfortunately, despite the advantages of bonding such as high aesthetics and easy technique, this technique has disadvantages such as the accumulation of plaque, the creation of white lesions, and the breaking of the band. These weaknesses cause prolonged treatment and increase the duration of clinical work, and the cost of treatment. Several methods have been introduced to prevent the formation of biofilm and tooth decay. One of the methods is to add antimicrobial substances to the composite resin. The two substances used for this purpose are fluoride and chlorhexidine. It is believed that nanoparticles have high antibacterial properties due to their small size [40]. In addition to knowing the antibacterial effects of nanoparticles, their effects on the bond strength between bracket and composite or cement bond strength of orthodontic braces are also important.

Silver nanoparticles

Silver has attracted a lot of attention in Nano dentistry due to its antimicrobial properties. Adding silver nanoparticles in orthodontic adhesive, although it is useful due to its antibacterial properties, its effect on bond strength has been questioned. Previous studies show that adding silver nanoparticles to the adhesive can reduce the bond strength, and the bond strength is statistically significantly lower in brackets bonded with composites containing silver nanoparticles [41]. Degrazia *et al*. [42] reported that this decrease in band strength, although statistically significant, is clinically acceptable. In another study, silver nanoparticles were added to reinforced glass ionomer cement and it was concluded that the bond strength decreases with the increase of silver nanoparticles, although it is still acceptable [19].

In contrast to these findings, Blocher showed that the difference in bond strength between brackets bonded with conventional resin composite and resin composite with silver nanoparticles is not significant [43]. Akhavan *et al*. [44] investigated the effect of adding silver nanoparticles and Nano hydroxyapatite on the strength of orthodontic adhesive bonds. Their results showed that the addition of silver hydroxyapatite nanoparticles at the rate of 1 and 5% by weight increases the bond strength, but the addition of nanoparticles at the rate of 10% by weight decreases the bond strength. Two studies showed that the use of silver nanoparticles in the cement of orthodontic bands, although it can slightly reduce the strength of the band, but its strength is still clinically acceptable. Other mechanical properties such as ultimate transverse strength and modulus are similar [45].

Titanium oxide

In recent decades, much attention has been paid to the photocatalytic properties of this particle. Studies have shown that this Nano valley has antibacterial properties and adding it to the adhesive can strengthen the mechanical properties, while the bond strength is equal to or higher than the control group of the study [41].

Studies on adding this nanoparticle to orthodontic adhesives have conflicting results. Felemban *et al*. [46] did not observe any significant difference in bond strength and ARI index between two groups of brackets bonded with an adhesive containing titanium oxide nanoparticles and a conventional adhesive. The study of Reddy *et al*. [41] showed that brackets bonded with adhesive containing titanium oxide nanoparticles have the lowest bond strength. Another study on the effect of adding titanium oxide/zinc oxide nanoparticles to Transbond XT adhesive showed that the adhesive with titanium oxide and zinc oxide tattoo particles has higher compressive strength, bond strength, and tensile strength [46].

The results of a study on the addition of these nanoparticles to the ionomer class showed that the tattoo of titanium particles in glass ionomer luting and base and repair do not change the bond strength [33].

Sepiolite

Sepiolite is a material with a needle-shaped crystal structure, which is formed from the binding of phyllosilicate. One of the new uses of this material is to use it as a nanofiller. This material causes interaction between nanofiller-nanofiller and nanofiller-matrix due to having active areas on its surface. Due to the excellent properties of adhesion and compatibility with the matrix, as well as unique properties, this nanoparticle also strengthens the manufactured polymer. The effects of adding Nano sepiolite particles to Dentin bond materials were investigated. The results have shown that this nanoparticle increases the bond strength of dentin bonding to dentine (with increasing nanoparticle concentration, the bond strength also increased), the maximum increase in bond strength was obtained with a concentration of 1%, the highest concentration studied [47]. So far, there has been no study on the application of this nanoparticle in the field of orthodontics.

Curcumin

This substance is obtained from the turmeric plant and in addition to using it as a spice, it is used as an herbal medicine in the treatment of diseases. This substance inhibits the growth of many bacteria such as staphylococcus and lactobacillus. In the study of Sodagar *et al*. [4], the addition of 1% by weight of curcumin nanoparticles to orthodontic composite is suggested without negative effects on bond strength and with good antimicrobial effects, although curcumin's insolubility is considered an important disadvantage.

Chitosan

Chitosan nanoparticles are obtained from the distillation of quinine and exist as a biopolymer in fungi and some plants.

Due to its anti-viral, anti-fungal, and anti-microbial properties, this substance is used in many fields such as the food industry, pharmaceutical industry, agriculture, cosmetics, and dentistry [48]. Sodagar *et al*. [48] in a study they conducted on the addition of chitosan nanoparticles to orthodontic adhesives concluded that all its concentrations have antimicrobial properties against *Streptococcus mutans* and *Streptococcus sangulis*. There was no statistically significant difference in the bond strength of brackets bonded with chitosan nanoparticles composite with the control group. Therefore, the application of this nanoparticle, in addition to having antimicrobial properties, will not significantly affect the strength of the bond.

Zinc oxide

The bond strength of brackets bonded with an adhesive containing this nanoparticle is significantly lower than the bond strength of brackets bonded with conventional composite [41].

Application of nanoparticles to prevent caries

Caries around orthodontic brackets are a significant clinical problem. Several methods have been introduced to prevent the formation of biofilm and tooth decay. One of the methods is to add antimicrobial substances to the composite resin. The two substances used for this purpose are fluoride and chlorhexidine [48]. It has been shown that fluoride-releasing nanofilled composites release fluoride as much as fluoride-releasing microfilled composites. Therefore, the addition of fluoride-releasing nanofield particles to the composite to reduce caries is not supported [49].

Another way to reduce decay is to add materials with the property of releasing calcium and phosphate to the composite, among these materials, ACP can be mentioned. The most important disadvantage of ACP is its poor mechanical properties. ACP nanoparticles can have two times stronger mechanical properties than ACP microparticles while releasing calcium and phosphate. A previous study has shown that in the ACP-NPS adhesive group, up to six months after bracket bonding, both the mineral content is higher and the number of *Streptococcus mutans* is lower. Therefore, the use of ACP-MPS adhesive is recommended. Another material that can continuously release calcium and phosphate is a chargeable cement containing amorphous calcium and phosphate nanoparticles. Refillable cement is made of glycerol dimethacrylate (PMGDM) and ethoxylated bisphenol dimethacrylate (EBPADMA). The new (uncharged) cement has the same bond strength as conventional orthodontic cement. The calcium and phosphate charging solution is made of CaCl2 and K2HPO4. This cement can release calcium and phosphate for 14 days after a one-minute immersion in the charging solution that is repeated three times a day [50].

Microleakage under orthodontic braces can be a cause of caries. It has been shown that glass ionomer cement modified with nano-hydroxyapatite can significantly reduce microleakage [51].

Application of nanoparticles to reduce friction between wire and bracket

As the teeth slide along the archwire, force is required to achieve the goal, to overcome the resistance created by contact with the bracket, and to produce the bone remodeling required for tooth movement. Unfortunately, the reaction of both forces, i.e. friction resistance and the force of teeth movement, is transferred to the teeth of the anchorage unit. Studies have shown that the frictional force is large under the best conditions. For example, if a canine tooth wants to be moved to close the space caused by the extraction of a tooth, 100 grams of force will be needed to move the tooth and 100 grams to overcome the frictional resistance, so the total force required to move the tooth is twice as large as the force that we expect [52].

Zinc oxide

Covering 0.016-inch steel wire with nano zinc oxide particles reduces the amount of friction by 39% during sliding in the metal bracket. Coating orthodontic wires with zinc oxide nanoparticles also reduces sliding resistance in ceramic brackets. Simultaneous coating of orthodontic wire and bracket or zinc oxide nanoparticles has not shown such an effect [53].

Titanium oxide nanoparticles and silver nanoparticles

Adding titanium oxide nanoparticles to the stainless steel bracket significantly increases the friction between the wire and the bracket, and therefore, they are not recommended for bracket coating. Coating steel brackets with silver nanoparticles also increases friction insignificantly, so the evidence about them is inconclusive [24].

Application of nanoparticles to investigate the physical properties of acrylic

In recent years, much attention has been paid to the use of nanoparticles in acrylic. These materials are the main components of moving plates. Besides investigating the antimicrobial properties, it is important to know the effects of these nanoparticles on the physical properties of acrylic.

Silver

The results of studies on adding silver nanoparticles to acrylic are contradictory. These nanoparticles have been shown to increase the flexural strength of Selecta Plus acrylic, but further additions again decrease the flexural strength. In the case of rapid acrylic, the opposite of this situation occurs, that is, by adding nanoparticles, the bending strength first decreases, but it increases again to the initial bending strength. Therefore, the effect of adding silver nanoparticles on the bending strength of acrylic depends on the type of grill and the percentage of adding silver nanoparticles [54].

Tio2 and Sio2

Adding nanoparticles of titanium oxide or silicon oxide to acrylic reduces the bending strength and this reduction is directly related to the dose of nanoparticles. The difference in flexural strength between acrylic-containing titanium oxide nanoparticles and silicon oxide nanoparticles is not statistically significant. Although acrylic with titanium oxide shows less strength than silicon oxide [36].

Application of nanoparticles to make orthodontic adhesive visible (Visibility)

After finishing the orthodontic treatment, it is necessary to remove the brackets and any remaining adhesive. However, since the orthodontic adhesive is the same color as the tooth, it can be difficult to remove it. During the removal of adhesive with rotary devices, there is a possibility of damaging the enamel [55]. The addition of europium particles to a network of zinc oxide nanoparticles can characterize the remaining composite after deboning the brackets with ultraviolet or near-ultraviolet light irradiation [56].

Conclusion

According to the studies, all silver nanoparticles, curcumin, titanium oxide, chitosan, zinc oxide, and tetravalent ammonium derivatives show good antibacterial properties. Silver nanoparticles added to orthodontic composite reduce bond strength. However, more studies are needed to determine the clinical adequacy of the bond strength of brackets bonded with composite containing silver nanoparticles. It seems that curcumin and chitosan nanoparticles do not hurt bond strength, but the Sepiolite nanoparticles increase bond strength. The results regarding the bond strength of titanium oxide nanoparticles are contradictory. To investigate the effect of each of these nanoparticles with high band strength, more studies are recommended. Although adding ACP nanoparticles and a chargeable cement of calcium phosphate nanoparticles to the composite caused regular release of calcium and phosphorus ions, fluoride nanoparticles did not show a positive effect in reducing caries. Therefore, new studies are recommended for further investigation. Studies show that adding zinc oxide nanoparticles to orthodontic wires reduces the friction between the wire and the bracket. While adding titanium oxide nanoparticles to the bracket increases the friction. No study has been done on other nanoparticles so far. Regarding the investigation of the effect of nanoparticles on the physical properties of acrylic, there are insufficient studies and no definitive conclusions. One of the important aspects of the use of nanoparticles is their toxicity. Although the evidence in this field is insufficient, it seems that nanoparticles are at least not more toxic than conventional substances. Due to the large scope of the nanotechnology field and the lack of studies on the effects of nanoparticles on the strength of orthodontic adhesive bonds, fluoride release, the effect on wire and bracket friction, as well as the physical properties of orthodontic acrylics, more studies are suggested to clarify these aspects.

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