# Antibacterial Coatings for Orthodontic Materials: A review

Madhura Rao[1], Ashith M V[1]*, Supriya Nambiar[1], Shravan Shetty[1], Asavari Desai[1], Nidhin Philip Jose[1]

1. Department of Orthodontic and Dentofacial Orthopaedics, Manipal College of Dental Sciences Mangalore, Affiliated to Manipal Academy of Higher Education, Manipal. Pincode-575001.

**Abstract**

White spot lesions are the most common iatrogenic effect observed post orthodontic treatment. These white spot lesions are opacities observed on the tooth surface that occur due to demineralization of the enamel surface. Since this is an irreversible effect, it becomes a great burden to both the orthodontic practitioners as well as patients to undo this lesion. It has been demonstrated that Streptococcus mutans, plays a crucial role in the initiation of white spot lesions by contributing to demineralisation of teeth, as the pH of the oral environment declines.

The aim of this review is to discuss about the retraction mechanism in orthodontics and to discuss in. The aim of this review article is to discuss the coating methods to fabricate antibacterial coatings and understand their application for coating orthodontic materials. The coated orthodontic materials help to reduce the growth of the oral bacteria thus preventing the formation of white spot lesions.

The various coating methods followed by different approaches to coat the orthodontic archwires, brackets, TADS, adhesives, retainer, elastic and bands and clear aligners have been discussed.

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## Introduction

Teeth that are positioned improperly can negatively affect a person's appearance and oral and dental health and compromising patient's psychological self-esteem as well as self-confidence.[1]

The orthodontic molar bands, brackets, archwires, steel ligatures, elastics and other orthodontic appliances when placed in the oral environment for an extended period of time, ingested liquids and salivary flow, food temperature variations, and masticatory force have an cause friction or biocorrosion processes, altering their surface topography, microstructure, and mechanical properties thereby resulting in biofilm formation and dental plaque.[2,3] It has been demonstrated that *Streptococcus mutans,* plays a crucial role in the initiation of white spot lesions by contributing to demineralisation of teeth, as the pH of the oral environment declines. These white spot lesions are possibly irreversible and at the same time unhealthy and unesthetic.[4–10] To prevent the formation of white spot lesions, surface treatments and coatings have been developed to improve the surface properties and making these materials more oral cavity friendly for orthodontic procedures.[11]

***Corresponding author:***
Dr. Ashith M V
Professor
Department of Orthodontic and Dentofacial Orthopaedics
Manipal College of Dental Sciences, Mangalore
Affiliated to Manipal Academy of Higher Education, Manipal
Pincode-575001
E-mail: ashith.mv@manipal.edu

### Coating Methods:

Thermal and chemical methods are used to form the coatings on the orthodontic materials. Thermal methods include TPS and Vapor deposition and Chemical Methods include Electrodeposition, Electrophoresis and Solgel Method.

### Antibacterial Coatings On Orthodontic Archwires

#### I. Surface modification of Orthodontic Wires:

Mhaske et al. 2015 examined antibacterial and adhesion capabilities of NiTi as well as silver-coated stainless steel orthodontic wires against Lactobacillus acidophilus.. Eight test groups with a total of 10 specimens each comprised the 80 NiTi orthodontic wire and stainless steel specimens were used. Control group consisted of uncoated wires. In conclusion, the silver-coated orthodontic wires demonstrated an antibacterial effect against the *Lactobacillus acidophilus* compared to the wires which were uncoated. [12]

**II. Photocatalytic titanium oxide:**

Baby et al. 2017 evaluated cytotoxic and antimicrobial properties of the photocatalytic titanium oxide coated stainless steel orthodontic brackets. 68 stainless steel brackets from the total sample of 115 brackets, were coated with titanium oxide using a radiofrequency magnetron sputtering device. The microbiologic tests were used to evaluate the antibacterial activity of the orthodontic brackets against the *Streptococcus mutans*. The anatase phase of the titanium oxide showed negligible cytotoxity with significant antibacterial property hence advised for coating orthodontic brackets. [13]

**III. Lysozyme- coated Composite arch wires:**

He et al. investigated antibacterial characteristics, sensitivity to the corrosion and the in vitro cytotoxicity of the lysozyme-coated Composite arch wires(CAW) synthesized using liquid phase deposition. They concluded that the lysozyme coatings on the CAW surfaces enhanced biocompatibility and provided varying degrees of antibacterial activity against the *Staphylococcus aureus.* While different lysozyme concentrations demonstrated different protective benefits, the optimal lysozyme concentration for CAW coatings may be 40 g L.

**IV. N- doped TiO2 nanocrystal thin film on Composite Arch Wires:**

Liu et al. 2017 covered CAWs with a nanocrystal thin film, namely an N-doped $TiO_2$ thin film, can greatly increase their corrosion resistance and antibacterial capabilities. The bacterial culture was used to evaluate the samples' antibacterial capabilities against *Streptococcus mutans* which indicated that Composite Arch Wires coated in N-doped $TiO_2$ had the best antibacterial property. [14]

**V. Biomimetic approach for Orthodontic Archwires:**

Arango-Santander et al. 2013 following a biomimetic approach to modify orthodontic archwires and to evaluate the addition of bacteria on these orthodontic archwires. 0.017 × 0.025, which are 10 mm-long NiTi and 316L stainless steel orthodontic archwire fragments comprised the sample. The surface of Colocasia esculenta (L) Schott leaves was duplicated and a polydimethylsiloxane (PDMS) stamp was made for use in soft lithography. Topography transfer to the archwire was done using a silica sol. *Streptococcus mutans* was used to evaluate the bacterial adhesion. Results showed a decreased adhesion of *Streptococcus mutans* to the the modified archwires which was statistically significant [11]

**VI. $TiO_2$ coated Orthodontic Archwires**:

Mollabashi et al. 2020 assessed the adhesion *of Streptococcus mutans* on the stainless steel orthodontic wires coated with titanium dioxide to reduce the formation of white spots. They proved that stainless steel orthodontic wires with a thin layer of titanium dioxide coating had lower S. mutans colony counts in the first and third weeks thus proving effective at initial wire insertion.[15]

**VII. ZnO nanoparticles coated Orthodontic Archwires:**

Kachoei et al 2016 prepared nickel-titanium (NiTi) coated with friction-reducing and antibacterial zinc oxide (ZnO) nanoparticles coating. On the nickel-titanium (NiTi) wire, zinc oxide (ZnO) nanoparticles were used to create a friction-reducing and antimicrobial coating thus demonstrating good antibacterial and biological capabilities and provide safer treatment alternatives.[16]

**VIII. Photocatalytic TiO2 coated Orthodontic Archwires:**

Shah et al. 2011 and Chun et al. 2007 Orthodontic wires and brackets made of photocatalytic $TiO_2$-coated stainless steel have been examined for their anti-adherent and antibacterial capabilities. It was found that these materials are bactericidal against L. acidophilus and S. mutans. The $TiO_2$ nanoparticles' photocatalytic characteristics enable them to effectively destroy the bacteria. However, due to damage to the genes of human cells and the tissues, the usage of $TiO_2$ nanoparticles under UV radiation is restricted. [9]

**Anitbacterial Coatings For Orthodontic Brackets**

**I. Silver Nanoparticles (AgNPs), Silver ions, Silver dioxide, Coating:**

Bürgers et al. 2009 concluded that small silver nanoparticles, release more silver ions, promoting an antibacterial effect, whereas the histological effects of AgNPs typically concentrate on inhibiting microbial metabolism, impairing the specific bacterial processes as well as synthesis of extracellular polysaccharides. [17]

Arash et al 2017 studied the properties of orthodontic brackets made of stainless steel with a silver coating. An electroplating technique was used to coat the silver on the brackets in the case group. Disk diffusion and direct contact tests utilising the *Streptococcus mutans* strain were carried out at 3,6,24, and 48 hours, 15 and 30 days, to evaluate the antibacterial effect. They concluded that when exposed to Streptococcus mutans directly, brackets coated with Ag using the electroplating procedure demonstrated antibacterial capabilities. After contact with bacteria, the antibacterial effect persisted for 30 days [18]

Gilani et al 2017 investigated orthodontic brackets coated with silver dioxide for their antiadherent and antbacterial effects of against S. mutans on the coated and uncoated brackets were subsequently evaluated using microbiological techniques. They found that since $AgO_2$ brackets had antibacterial effect on Streptococcus mutans [19]

**II. Copper Oxide and Zinc Oxide:**

Yassaei et al., concluded that when silver nanoparticles were compared to copper oxide (CuO) nanoparticles, they showed no statistical significant difference. However, compared to silver, the curing time for copper material was longer. In addition to being less expensive, the former is also more stable chemically and physically than the latter.Copper and copper-zinc nanoparticles had a significant antibacterial effect on the microbes.

Kachoei et al., Behroozian et al. and Goto et al showed that the frictional forces between brackets and the archwires significantly reduced after ZnO nanoparticle coating**.** As a result, these nanoparticles present new possibilities for prevention of undesirable frictional forces and improved anchorage control with decreased resorption risk**.** [16,20]

**III. Nitrogen-Doped Titanium Dioxide (N-Doped $TiO_2$):**

OH was produced as a result of the activation of N-doped $TiO_2$. Free radicals, peroxyl radicals, hydrogen peroxide ($H_2O_2$), superoxide ions ($O_2$), and hydrogen peroxide. These chemicals are responsible for antimicrobial activity. They are also capable of reacting with proteins, enzymes and lipids.[21]

Poosti et al., 2013 showed that light cure orthodontic composite paste at concentrations of 1, 2 and 3% containing $TiO_2$ nanoparticles with a size 21±5, all had comparable antibacterial properties. [22]

Salehi et al. 2018 compared uncoated stainless steel brackets to nitrogen-doped $TiO_2$ brackets. The study concluded that the coated brackets displayed better antimicrobial activity against normal oral pathogenic bacteria. Adhesives' antibacterial activity is increased by adding $TiO_2$ while maintaining their mechanical integrity**.** [23]

Ghasemi et al 2017 conducted a preliminary investigation to evaluate the surface roughness, frictional resistance, and antibacterial effectiveness of nanofilms of silver and titanium oxide coated on stainless steel orthodontic brackets. It was observed that surface roughness and bacterial count significantly decreased after 3h with 60- and 100-mm films of silver and titanium oxide. To reduce the bacterial activity, both of these ions can be applied to all the surfaces of the bracket surfaces except for the slots. The slots coated with these nanofilms enhance friction. [18]

**Antibacterial Coated Orthodontic Temporary Anchorage Devices**

**I. AgNP coated TADs:**

Venugopal et al. 2017 titanium microimplants which are surface-treated with silver nanoparticles can be used to obtain antibacterial effect. They concluded that Ti-BP-AgNPs surface had excellent antibacterial activity towards the *A. actinomycetemcomitans, Streptococcus mutans, Streptococcus sanguinis* thus making these coated microimplants an excellent implantable biomaterial. [24]

**II. Chitosan modified TADs:**

Khanh Ly et al. 2019 attempted to improve the bioactive and antibacterial capabilities of the mini-implants by altering their surface with chitosan, hence increasing their lifespan. Improved adhesion and proliferation of chitosan-modified TI specimens (TI-SA-Ch) demonstrated a superior biocompatibility with pre-osteoblastic MC3T3-E1 cells. Their results concluded that TADs modified with chitosan can be used to enhance the antibacterial and bioactive properties of orthodontic microimplants, thereby improving their stability when placed in the jaw bone. [25]

Anggani et al. 2021 assessed the impact

of chitosan coating on *Porphyromonas gingivalis* biofilm formation on orthodontic mini implant.[25] orthodontic mini-implants were used. The implants were coated with chitosan, chitosan–azithromycin, azithromycin and uncoated samples which were not exposed to *Porphyromonas gingivalis*. The biofilms were discovered on the orthodontic micro implant's surface after 24 hours of incubation with the azithromycin-treated group showing the best biofilm mass inhibition. Therefore, *P. gingivalis* biofilm production was only successfully inhibited by orthodontic micro implants covered with chitosan, azithromycin or chitosan + azithromycin. [26]

**Antibacterial Coatings For Orthodontic Adhesives**

**I. ZnO-Nanoparticle And N Chitosan Containing Orthodontic Composite:**

Amir et al. ZnO nanoparticles and N Chitosan incorporated orthodontic composites were assessed for their antibacterial properties. ZnO-NPs and CS-NPs were tested against . *Lactobacillus acidophilus*, *Streptococcus sanguis and Streptococcus mutans,* cultured both planktonically and as a biofilm on composites in four groups to determine their antibacterial efficacy.

**II. (BMIM.NTf2) coated Orthodontic Adhesives:**

Garcia et al 2004 studied the effects of the different antibacterial compound concentrations of the 1-n-butyl-3-methylimidazoilium bis(trifluoromethanesulfonyl)imide (BMIM.NTf2) which were incoroporated into orthodontic adhesives. They concluded that the addition of BMIM.NTf2 at a 5 weight percent concentration did not alter the properties of the adhesives and it provided antibacterial activity without having any harmful effects on human keratinocytes.[27]

**III. Nanoparticles coated Orthodontic Composites:**

Yassaei et al, examined the antibacterial activity of orthodontic composites incorporated with various nanoparticles against the Streptococcus mutans at different times. At 0.5 percent and 1 percent weight concentrations, titanium oxides, hydroxyapatite, copper oxides, silver oxide and zinc oxide nanoparticles were synthesized. They concluded that adding 1% copper oxide and 1% silver oxide has temporary antibacterial property but did not support their therapeutic application.

**IV. Chitosan**

Mirhashemi et al. 2021 added chitosan to composite in combination with zinc oxide at a concentration of 10% composite decreased the formation of biofilm.

Toodehzaeim et al. 2015 CuO nanoparticles inhibited the growth of S. mutans when added to Transbond XT in concentrations of 0.01 percent, 0.55 percent, and 1 percent by weight. It was concluded that stronger antibacterial effect was obsereved with increased concentrations of CuO nanoparticles . [28]

**V. Quaternary ammonium salts on Orthodontic Adhesives:**

Liu et al. 2018 evaluated the antibacterial activity, remineralization effect and bonding performance, of the orthodontic adhesive containing 2-methacryloxylethyl dodecyl methyl ammonium bromide (MAE-DB) on ename which is an example of a polymerizable quaternary ammonium salt and nanoparticles of amorphous calcium phosphate (NACP). 80 non-carious human premolars were used and divided into 3 groups. They concluded that PND adhesive : PEHB + 40% NACP + 5% MAE-DB exhibited both antibacterial as well as remineralizing properties. The addition of the salts did not alter the bond strength and eliminated white spot lesions and dental caries.[29]

Shahar et al. investigated antibacterial action against *Streptococcus mutans* by orthodontic cements infused with insoluble antibacterial polycationic nanoparticles at a concentration of 1%. Polycationic polyethyleneimine (PEI)-based nanoparticles were incorporated into the orthodontic cements. GC Fuji Ortho LC cementand Neobond adhesive incorporated with 1% insoluble polycationic nanoparticles showed stable antibacterial effect with special consideration to direct contact between the adhesive and cement. The modified orthodontic cements can therefore prevent the growth of *Streptococcus mutans* adjacent to orthodontic appliances.

Sharon et al. 2018 investigated the antimicrobial activity of orthodontic cement containing quaternary ammonium polyethylenimine (QPEI) nanoparticles against the *Lactobacillus casei* and *Streptococcus mutans.* On the buccal aspect of the lower incisors that were extracted, orthodontic brackets were bonded. Neobond bracket adhesive orthodontic cement with and without QPEI nanoparticles were tested for their antibacterial efficacy. Crystal violet staining and bacterial count (CFU/mL) determined the antibacterial action. Thus, the study demonstrated that orthodontic cement with QPEI nanoparticles inhibited bacteria surrounding the orthodontic brackets. [30]

**VI. Silver nanoparticle and quaternary ammonium compounds coated orthodontic cements:**

Zhang et al. incorporated Dimethylaminohexadecyl methacrylate (DMAHDM), 2-methacryloyloxyethyl phosphorylcholine (MPC) and silver nanoparticles (NAg) into resin-modified glass ionomer cement (RMGI). The antibacterial properties of RMGI with triple agents (MPC + DMAHDM + NAg) were substantially greater than those of RMGI with single agents or double agents, according to the investigation of 9 groups of cements. When compared to the commercial control, the bacterial count was minimal on the RMGI along with triple agents. [31]

Chen et al. added 2-methacryloyloxyethyl phosphorylcholine (MPC), Nacetylcysteine (NAC) and silver nanoparticles (NAg) to the commercial resin-modified glass ionomer cement (RMGIC) and studied their effects on biofilms, biocompatibility and bonding strength. The unmodified RMGIC served as the control. The modified cements demonstrated significant antibacterial, protein-repellent, and acceptable biocompatibility properties. [32]

**VII. Bioactive Glass Containing Orthodontic Bonding Agents:**

Kim et al. 2018 assessed the remineralization effect and the antibacterial activity of the silver- or zinc-doped bioactive glass (BAG) added to the orthodontic adhesives. The biological and mechanical properties of these agents were also studied. They concluded that the modified orthodontic adhesives with zinc- or silver-doped BAG had better antibacterial effect as well as remineralization property. [33]

**Antibacterial Coatings For Retainers, Elastics And Bands**

**I. Coated Wires for Retainers:**

Morita et al. 2014 coated stainless steel and titanium fixed orthodontic retainer wires with silver ions and studied its effect on three species of periodontopathic bacteria and two species of the cariogenic bacteria. Examination of the two Volatile Sulfur Compound gases produced by the *Porphyromonas gingivalis* and the biofilms of the bacteria *Streptococcus sobrinus* were carried out. Radial diffusion tests showed a diameter >2-mm bacterial growth-resistant zone on all the silver ion-coated wires indicating that even in the initial stages of culture, a basic silver ion coating on the pure stainless steel and titanium wires limited the growth as well as pathogenic activities of the oral pathogens. [34]

**II. Coated Orthodontic Elastomeric Modules:**

Gomora et al. 2017 studied the effects of silver nanoparticles (AgNPs) coated orthodontic elastomeric modules (OEMs) using extract from Hetheroteca inuloides (H. inuloides) which is a plant based bioreductant. Agar diffusion tests were used to assess OEM coated with AgNPs' antibacterial abilities against the clinical isolates of *Lactobacillus casei, Escherichia coli, Streptococcus mutans* and *Staphylococcus aureus* and they demonstrated inhibition halos suggesting that coated elastomeric modules may have antibacterial properties.[35]

Jeon et al 2015. Chlorhexidine (CHX) and orthodontic elastomerics were found to be the most effective combination for preventing oral disease in orthodontic patients. The polymer utilised was ethyl cellulose (EC). Based on variations in solvent, the experimental group consisted of five groups. In Group 3 i.e, Chlorhxidine diacetate + Ethyl Cellulose + 30% ethanol 70% Dichloromethane showed antimicrobial release increased over time for 48 h with the longest sustained-release property along with highest antibacterial characteristics, which were verified by inhibition zone testing with S. mutans displaying successful antibacterial action.[36]

**III. Coated Orthodontic Bands:**

Prabha et al. 2016 coated stainless steel bands with silver nanoparticle (SNP). Thermal evaporation technology was used for the purpose of coating. Gram-positive bacteria were used to test the coated band material's antimicrobial effectiveness. The SNP coated dental bands demonstrate potential antimicrobial activity. [37]

**Antibacterial Coatings For Clear Aligners**

Xie et al. 2020 prevented bacterial accumulation surrounding the orthodontic appliances by using stable quaternary ammonium- modified gold nanoclusters (QA-

GNCs) which are highly stable. This technique could be used to eliminate potential bacterial infections on a variety of additional medical devices.[38]

Park et al. 2018 coated clear overlay appliances (COAs) with an antibacterial coating. A layer-by-layer (LbL) approach and crosslinking techniques were used to fabricate the multilayer film made of chitosan (CHI) and carboxymethylcellulose (CMC) to create the polysaccharide coating on these clear overlay appliances. The biocompatibility of the coating was enhanced with inhibition of bacterial adhesion. [39]

Worreth et al. 2022 used cinnamaldehyde to test its antibacterial characteristics in clear aligners for minor orthodontic treatment. Bacterial biofilms growth was investigated using isothermal microcalorimetry. At 12 and 24 hours, calorimetric data analysis was done to calculate the inhibition by *Staphylococcus epidermidis*, *Streptococcus mitis* and *Streptococcus mutans* clinical isolates. 70% reduction in the growth rate of *Staphylococcus epidermidis* was observed and the lag phase for the same was prolonged by 12 hrs. The growth rate for *Streptococcus mitis* and *Streptococcus mutans,* declined by 10% and 20%, respectively and their lag phase lengthened by 2 and 6 hrs respectively.[40]

## Conclusions

Debonding and cleaning of the adhesive remnants causes enamel crystal demineralization and damage to the tooth enamel surface. The enamel contour become rough, increasing the risk of bacterial attachment and plaque accumulation on the enamel surface. [41] The objective of improving surface qualities has led to the development of a variety of coating processes and materials. Some coating issues have developed, most notably the delamination or wear of the coating. However, ongoing research have improved methods to enhance the qualities of metallic biomaterials. To date, the approach used is mainly in vitro to assess the biological qualities of coated substrates, the behavior of the coatings, and the mechanical properties of both the coatings and the substrates and studies need to be performed in vivo to get a better understanding of the procedures and how they react with the human body.

## Declaration of Interest

The authors report no conflict of interest.

## References

1. Savoldi F, Papoutsi A, Dianiskova S, Dalessandri D, Bonetti S, Tsoi JKH, Matinlinna JP, Paganelli C. Resistance to sliding in orthodontics: misconception or method error? A systematic review and a proposal of a test protocol. Korean J Orthod 2018 Jul;48(4):268-280.
2. Papaioannou W, Gizani S, Nassika M, Kontou E, Nakou M. Adhesion of Streptococcus mutans to Different Types of Brackets. Angle Orthod. 2007 Nov 1;77(6):1090–5.
3. Ahn SJ, Lee SJ, Kook JK, Lim BS. Experimental antimicrobial orthodontic adhesives using nanofillers and silver nanoparticles. Dental Materials. 2009 Feb 1;25(2):206–13.
4. Arab S, Malekshah SN, Mehrizi EA, Khanghah AE, Naseh R, Imani MM. Effect of Fixed Orthodontic Treatment on Salivary Flow, pH and Microbial Count. J Dent (Tehran) 2016 Jan;13(1):18-22.
5. Oh KT, Joo UH, Park GH, Hwang CJ, Kim KN. Effect of silver addition on the properties of nickel-titanium alloys for dental application. J Biomed Mater Res B Appl Biomater . 2006 Feb;76(2):306-14.
6. Min Cho, Hyenmi Chung, Wonyong Choi, Jeyong Yoon. Linear correlation between inactivation of E. coli and OH radical concentration in TiO2 photocatalytic disinfection. Water Res 2004; 38(4):1069-77.
7. Saint S, Elmore J, Sullivan S, Emerson S, Koepsell T. The efficacy of silver alloy-coated urinary catheters in preventing urinary tract infection: a meta-analysis. American Journal of Medicine, 1998; 105(3):236-41.
8. Lakshmi S, Renganathan R, Fujita S. Study on TiO2-mediated photocatalytic degradation of methylene blue. J Photochem Photobiol A Chem. 1995 May 31;88(2–3):163–7.
9. Shah AG, Shetty PC, Ramachandra CS, Bhat NS, Laxmikanth SM. In vitro assessment of photocatalytic titanium oxide surface modified stainless steel orthodontic brackets for antiadherent and antibacterial properties against Lactobacillus acidophilus. Angle Orthod. 2011 Nov 1;81(6):1028–35.
10. Corbett JA, Brown LR, Keene HJ, Horton IM. Comparison of Streptococcus mutans concentrations in non-banded and banded orthodontic patients. J Dent Res.1981 Dec;60(12):1936-42.
11. Arango S, Peláez-Vargas A, García C. Coating and Surface Treatments on Orthodontic Metallic Materials. Coatings 2013; 3(1):1-15
12. Mhaske AR, Shetty PC, Bhat NS, Ramachandra CS, Laxmikanth SM, Nagarahalli K, et al. Antiadherent and antibacterial properties of stainless steel and NiTi orthodontic wires coated with silver against Lactobacillus acidophilus—an in vitro study. Progress in Orthodontics 2015, 16(40):1-6.
13. Baby RD, Subramaniam S, Arumugam I, Padmanabhan S. Assessment of antibacterial and cytotoxic effects of orthodontic stainless steel brackets coated with different phases of titanium oxide: An in-vitro study. Am J Orthod Dentofacial Orthop 2017 Apr;151(4):678-684.
14. Liu J, Lou Y, Zhang C, Yin S, Li H, Sun D, et al. Improved corrosion resistance and antibacterial properties of composite arch-wires by N-doped TiO2 coating. RSC Adv. 2017;7(69):43938–49.
15. Mollabashi V, Farmany A, Alikhani MY, Sattari M, Soltanian AR, Kahvand P, Banisafar Z. Effects of TiO 2-Coated Stainless Steel Orthodontic Wires on Streptococcus mutans Bacteria: A Clinical Study. Int J Nanomedicine 2020 Nov 10;15:8759-8766.
16. Behroozian A, Kachoei M, Khatamian M, Divband B. The effect of ZnO nanoparticle coating on the frictionalresistance between orthodontic wires and ceramic brackets. J Dent Res Dent Clin Dent Prospects. 2016 Jun 15;10(2):106–11.

17. Bürgers R, Eidt A, Frankenberger R, Rosentritt M, Schweikl H, Handel G, Hahnel S. The anti-adherence activity and bactericidal effect of microparticulate silver additives in composite resin materials. Arch Oral Biol 2009 Jun;54(6):595-601.
18. Ghasemi T, Arash V, Rabiee SM, Rajabnia R, Pourzare A, Rakhshan V. Antimicrobial effect, frictional resistance, and surface roughness of stainless steel orthodontic brackets coated with nanofilms of silver and titanium oxide: a preliminary study. Microsc Res Tech. 2017 Jun;80(6):599-607.
19. Gilani RA, Laxmikanth SM, Ramachandra CS, Prasad SL, Shetty S, Vasudevan SD. Antibacterial and antiadherent properties of silver dioxide-coated brackets: Journal of Indian Orthodontic Society. 2017;51:9-14.
20. Goto M, Kasahara A, Tosa M. Low-Friction Coatings of Zinc Oxide Synthesized by Optimization of Crystal Preferred Orientation. Tribology Letters 2011;43(2):155-162.
21. Zakrzewski W, Dobrzynski M, Dobrzynski W, Zawadzka-Knefel A, Janecki M, Kurek K, et al. Nanomaterials Application in Orthodontics. Nanomaterials 2021;11(2):337.
22. Poosti M, Ramazanzadeh B, Zebarjad M, Javadzadeh P, Naderinasab M, Shakeri MT. Shear bond strength and antibacterial effects of orthodontic composite containing TiO2 nanoparticles. Eur J Orthod 2013 Oct;35(5):676-9.
23. Salehi P, Babanouri N, Roein-Peikar M, Zare F. Long-term antimicrobial assessment of orthodontic brackets coated with nitrogen-doped titanium dioxide against Streptococcus mutans. Prog Orthod 2018 Sep 17;19(1):35.
24. Venugopal A, Muthuchamy N, Tejani H, Gopalan AI, Lee KP, Lee HJ, et al. Incorporation of silver nanoparticles on the surface of orthodontic microimplants to achieve antimicrobial properties. Korean J Orthod 2017 Jan;47(1):3-10.
25. Ly NTK, Shin H, Gupta KC, Kang IK, Yu W. Bioactive Antibacterial Modification of Orthodontic Microimplants Using Chitosan Biopolymer. Macromolecular Research 2019; 27: 504-510.
26. Anggani HS, Perdana RG, Siregar E, Bachtiar EW. The effect of coating chitosan on Porphyromonas gingivalis biofilm formation in the surface of orthodontic mini-implant. J Adv Pharm Technol Res 2021 Jan-Mar;12(1):84-88.
27. Martini Garcia I, Jung Ferreira C, de Souza VS, Castelo Branco Leitune V, Samuel SMW, de Souza Balbinot G, et al. Ionic liquid as antibacterial agent for an experimental orthodontic adhesive. Dental Materials. 2019 Aug 1;35(8):1155–65.
28. Mirhashemi A, Ahmad Akhondi MS, Sodagar A, Jalali YF, Jazi L. Effect of nano–zinc oxide and nano-chitosan particles on the shear bond strength of dental composites used as orthodontic adhesive. J World Fed Orthod. 2021 Dec;10(4):172-176.
29. Liu Y, Zhang L, Niu L na, Yu T, Xu HHK, Weir MD, et al. Antibacterial and remineralizing orthodontic adhesive containing quaternary ammonium resin monomer and amorphous calcium phosphate nanoparticles. J Dent. 2018 May 1;72:53–63.
30. Sharon E, Sharabi R, Eden A, Zabrovsky A, Ben-Gal G, Sharon E, Pietrokovski Y, Houri-Haddad Y, Beyth N. Antibacterial Activity of Orthodontic Cement Containing Quaternary Ammonium Polyethylenimine Nanoparticles Adjacent to Orthodontic Brackets. Int J Environ Res Public Health 2018 Mar 27;15(4):606.
31. Zhang N, Melo MAS, Antonucci JM, Lin NJ, Lin-Gibson S, Bai Y, et al. Novel Dental Cement to Combat Biofilms and Reduce Acids for Orthodontic Applications to Avoid Enamel Demineralization.Materials (Basel). 2016 May 25;9(6):413.
32. Chen, M., Yi, J. & Zhao, Z. Biocompatible orthodontic cement with antibacterial capability and protein repellency. BMC Oral Health, 2021;21:412 .
33. Kim YM, Kim DH, Song CW, Yoon SY, Kim SY, Na HS, Chung J, Kim YI, Kwon YH. Antibacterial and remineralization effects of orthodontic bonding agents containing bioactive glass. Korean J Orthod 2018 May;48(3):163-171.
34. Morita Y, Imai S, Hanyuda A, Matin K, Hanada N, Nakamura Y. Effect of silver ion coating of fixed orthodontic retainers on the growth of oral pathogenic bacteria. Dent Mater J 2014;33(2):268-74.
35. Hernández-Gómora A, Lara-Carrillo E, Robles-Navarro JB, Scougall-Vilchis RJ, Hernández-López S, Medina-Solís CE, Morales-Luckie RA. Biosynthesis of silver nanoparticles on orthodontic elastomeric modules: evaluation of mechanical and antibacterial properties. Molecules. 2017 Aug 25;22(9):1407.
36. Jeon HS, Choi CH, Kang SM, Kwon HK, Kim BI. Chlorhexidine-releasing orthodontic elastomerics. Dent Mater J 2015;34(3):321-6.
37. Prabha RD, Kandasamy R, Sivaraman US, Nandkumar MA, Nair PD. Antibacterial nanosilver coated orthodontic bands with potential implications in dentistry. Indian J Med Res. 2016 Oct;144(4):580-586.
38. Xie Y, Zhang M, Zhang W, Liu X, Zheng W, Jiang X. Gold Nanoclusters-Coated Orthodontic Devices Can Inhibit the Formation of Streptococcus mutans Biofilm. ACS Biomater Sci Eng **2020;** *6* (2):1239-1246.
39. Park S, Kim H hye, Yang S bin, Moon JH, Ahn HW, Hong J. A Polysaccharide-Based Antibacterial Coating with Improved Durability for Clear Overlay Appliances. ACS *Applied Materials & Interfaces* **2018;** *10* (21): 17714-17721.
40. Worreth S, Bieger V, Rohr N, Astasov-Frauenhoffer M, Töpper T, Osmani B, Braissant O. Cinnamaldehyde as antimicrobial in cellulose-based dental appliances. J Appl Microbiology. 2022 Feb;132(2):1018-1024.
41. Ilham Khalid, Haru Setyo Anggani, Nada Ismah. Differences in Enamel Surface Roughness Changes after Debonding Using Resin Infiltration System and Nano-Filled Resin Coating. J Int Dent Med Res,2019, 12(1): 95-100.