Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Study on the role of nano antibacterial materials in orthodontics (a review)

Estudo sobre o papel dos materiais nanoantibacterianos na ortodontia

H. S. Budi[a], Madiha Fouad Jameel[b], G. Widjaja[c], Mukhalled Salim Alasady[d], Trias Mahmudiono[e], Y. F. Mustafa[f], I. Fardeeva[g] and M. Kuznetsova[h]

[a]Universitas Airlangga, Department of Oral Biology, Surabaya, Indonesia
[b]Al-Rafidain University College, Baghdad, Iraq
[c]Universitas Krisnadwipayana, Jatiwaringin, Indonesia
[d] Al-Ayen University, Scientific Research Center, Thi-Qar, Iraq
[e] Faculty of Public Health Universitas Airlangga, Trias Mahmudiono, Departemen of Nutrition, Indonesia
[f]University of Mosul, College of Pharmacy, Department of Pharmaceutical Chemistry, Mosul, Iraq
[g]Kazan Federal University, Kazan, Russia
[h]I.M. Sechenov First Moscow State Medical University (Sechenov University), Department of Propaedeutics of Dental Diseases, Moscow, Russian Federation

Abstract

Nanoparticles (NPs) are insoluble particles with a diameter of fewer than 100 nanometers. Two main methods have been utilized in orthodontic therapy to avoid microbial adherence or enamel demineralization. Certain NPs are included in orthodontic adhesives or acrylic resins (fluorohydroxyapatite, fluorapatite, hydroxyapatite, SiO_2, TiO_2, silver, nanofillers), and NPs (i.e., a thin layer of nitrogen-doped TiO_2 on the bracket surfaces) are coated on the surfaces of orthodontic equipment. Although using NPs in orthodontics may open up modern facilities, prior research looked at antibacterial or physical characteristics for a limited period of time, ranging from one day to several weeks, and the limits of in vitro studies must be understood. The long-term effectiveness of nanotechnology-based orthodontic materials has not yet been conclusively confirmed and needs further study, as well as potential safety concerns (toxic effects) associated with NP size.

Keywords: anti-caries activity, antimicrobial, health risk, orthodontics, nanoparticles.

Resumo

Nanopartículas (NPs) são partículas insolúveis com diâmetro inferior a 100 nanômetros. Dois métodos principais têm sido utilizados na terapia ortodôntica para evitar a aderência microbiana ou a desmineralização do esmalte: NPs são incluídas em adesivos ortodônticos ou resinas acrílicas (fluoro-hidroxiapatita, fluorapatita, hidroxiapatita, SiO_2, TiO_2, prata, nanopreenchimentos) e NPs são revestidas nas superfícies de equipamentos ortodônticos, ou seja, uma camada fina de TiO_2 dopado com nitrogênio nas superfícies do braquete. Embora o uso de NPs em ortodontia possa tornar acessível modernos recursos, pesquisas anteriores analisaram as características antibacterianas ou físicas por um período limitado de tempo, variando de 24 horas a várias semanas, por isso devem ser compreendidos os limites dos estudos in vitro. A eficácia de longo prazo de materiais ortodônticos com base em nanotecnologia ainda não foi confirmada de forma conclusiva, o que exige mais estudos, bem como potenciais preocupações de segurança (efeitos tóxicos) associadas ao tamanho da NP.

Palavras-chave: atividade anticárie, antimicrobiano, riesgo de salud, ortodôntica, nanopartículas.

1. Introduction

Using specific nanoparticles (NPs) as antibacterial agents in dentistry and medicine has gotten a lot of press. Insoluble particles smaller than 100 nanometers are referred to be nanoparticles (Moritz and Geszke-Moritz, 2013; Melo et al., 2013; Song and Ge, 2019; Yaseen et al., 2020). NPs particles have a higher surface-to-volume ratio (per unit mass) than non-nano scale particles. This allows them to interface more intimately with microbial membranes and offer a much bigger surface area for antimicrobial action (Borzabadi-Farahani et al., 2014). Antibiotic insistence is spreading among bacteria, and microorganisms are less likely to acquire insistence on metal nanoparticles than on traditional antibiotics (Bapat et al., 2019). Such findings have rekindled interest in the usage of different

*e-mail: widjaja_gunawan@yahoo.com; madiha.fouad.elc@ruc.edu.iq; trias-m@fkm.unair.ac.id
Received: October 7, 2021 – Accepted: November 12, 2021

antibacterial agents like metallic nanoparticles (see Table 1) (Schrand et al., 2010). Metal NPs in the 110 nm size range, in particular, has been demonstrated to have the most biocidal effect against bacteria (Shkodenko et al., 2020). The antibacterial characteristics of NPs were employed in the oral cavity to inhibit microbial adherence through two main mechanisms: mixing dental materials with NPs and covering surfaces with NPs, with the ultimate goal of decreasing biofilm development (Ansarifard et al., 2021). The research on using nanoparticles in orthodontics is few. Therefore, this study summarizes research that looked at the antibacterial and anti-caries properties of NPs in orthodontics.

2. Antimicrobial Nanoparticles Usage in Orthodontics for Managing Oral Biofilm

The development of white spots, sometimes called demineralization, is a common unintended consequence of orthodontic treatment (Figure 1). During active usage of the appliance, acidogenic plaque bacteria, such as lactobacilli and mutans streptococci, might impair the self-cleaning capacity of teeth, change the oral microbiota, and raise the amounts of acidogenic plaque bacteria in saliva and dental biofilm (Roig-Vanaclocha et al., 2020; Kidd and Fejerskov, 2004; Chen et al., 2020). Demineralization or dental decay surrounding orthodontic brackets can be caused by this cariogenic biofilm (Sudjalim et al., 2007; Gorton and Featherstone, 2003). Streptococcus mutans is the major aetiological element in developing and advancing tooth decay inside such a biofilm (Kamiya et al., 2011; Lemos et al., 2019). By offering retentive regions, braces, and fixed orthodontic equipment help germs accumulate. Enamel demineralization around the brackets has been reported in 50-70% of individuals receiving fixed orthodontic appliance treatment.

The 10-mm gaps at the adhesive enamel junction have been shown to have bacterial buildup. Several techniques for reducing demineralization and white spot development during therapy have been proposed, most of which are dependent on patient compliance (Pascotto et al., 2004). The use of fluoride or antimicrobial treatments, as well as mechanical plaque biofilm removal, is the mainstay (Mitwalli et al., 2021). In diverse types (i.e., incorporated into adhesives, professional application, toothpaste, mouthwash), Fluoride inhibits the caries-causing bacteria's metabolism and boosts enamel and dentine resilience (Nayak et al., 2019). In order to regulate the oral biofilm and decrease demineralization around the brackets, certain NPs have been introduced into orthodontic adhesives because of their anti-adhesive or biocidal properties (Mobeen et al., 2021). While using NPs in traditional orthodontic equipment and adhesives, the chemical and physical characteristics mustn't be harmed, else clinical performance will suffer (Bącela et al., 2020). Furthermore, the novel nano-adhesives' antiadhesive and antibacterial capabilities and their safety must be shown over a therapeutically relevant time period (George et al., 2016; Agnihotri et al., 2020). To profit from the specific features of particular NPs, orthodontic materials have been combined with NPs, or bracket surfaces have been coated with NPs thus far (Table 2). In the following, four types of examples will be shown.

Table 1. Some antibacterial nanoparticles that are widely utilized.

Nanoparticles
Copper (Cu/CuO)
Gold (Au)
Silica (SiO_2)
Silver (Ag)
Titania (TiO_2)
ZnO

2.1. Using a thin layer of nitrogen-doped TiO2 NPs to coat an orthodontic bracket

Titanium dioxide (TiO_2) photocatalysis has a long history (Wold, 1993; Chen and Selloni, 2014; Cuppini et al., 2019). TiO_2 NPs have higher hydrophilicity than untreated surfaces, which makes them more resistant to biofilm development. Because of remarkable aggregation caused by high surface energy, nano-sized TiO_2 powder is hard to disperse, affecting its antibacterial and physicochemical characteristics directly (Teubl et al., 2015). Salehi et al. (2018) studied the antibacterial and bacterial adhesion capabilities of brackets covered with a thin coating of nitrogen-doped TiO_2 NPs using visible light. TiO_2 can display catalytic action in the visible light range thanks to nitrogen doping and alteration. Hydrogen peroxide (H_2O_2), peroxyl radicals (HO_2), superoxide ions (O_2), and Free radicals (OH) are formed as a result of the activation. These compounds react with biological components, including nucleic acids, enzymes, proteins, and lipids, through a sequence of oxidation processes, causing damage to biological cell structures while simultaneously acting as antimicrobials. This study discovered that the anti-adhesive characteristics of the material were effective against Streptococcus mutans; the coated bracket's rate of antibacterial action against Streptococcus mutans. Such results have significance for enamel demineralization and gingivitis prevention throughout orthodontic treatment.

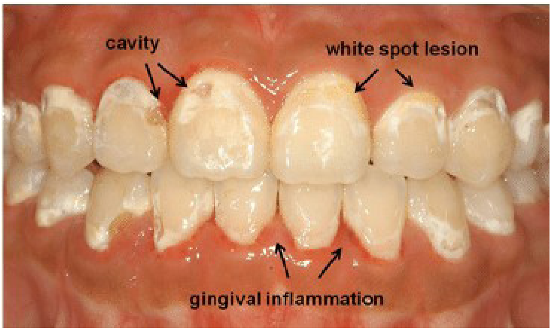

Figure 1. After the removal of a fixed orthodontic device, white spot lesions, cavities (upper dentition), and gingival irritation (lower dentition) are produced by orthodontic biofilms.

Table 2. Nanotechnology has been utilized to improve the antibacterial and anti-caries characteristics of orthodontic materials in the past.

Nano material used	Reference
Incorporating fluorapatite or fluorohydroxyapatite NPs into an orthodontic adhesive	Malik et al. (2018)
Nanofilled adhesive with silver nonoparticles	Degrazia et al. (2016)
Coating orthodontic bracket with a thin film of nitrogen-doped TiO_2 nanoparticles	Cao et al. (2013)
Nanofilled adhesive and nano-ionomer	Behnaz et al. (2018)
Incorporating hydroxyapatite NPs into an orthodontic cement	Enan and Hammad (2013)
Incorporating silver NPs into a PMMA resin	Sodagar et al. (2017)
Nanofilled adhesive	Morais et al. (2015); Nayak et al. (2015); Pai et al. (2012)
Incorporating TiO2 NPs into an orthodontic adhesive	Toodehzaeim et al. (2018)
Incorporating TiO_2 and SiO_2 NPs into a PMMA resin	Tandra et al. (2018)

Nevertheless, certain crucial data on the recently improved bracket surfaces' long-term clinical safety and effectiveness, as well as their impact on tooth bond strength, is absent.

2.2. Combining fluorapatite, fluorohydroxyapatite, or hydroxyapatite NPs with glass ionomer cement or resin-modified glass ionomer cement

Compared to glass ionomer cement, resin-modified glass ionomer cement (RMGICs) have a higher bond resistance while still allowing fluoride release (Godoy-Bezerra et al., 2006; Maruo et al., 2010; Pereira et al., 2013). Sharafeddin et al. (2020) investigated the impact of adding fluorohydroxyapatite particles (NFHA) or nano-sized fluorapatite (NFA) to an RMGIC.

Fluoride levels were also substantially higher in the NFHA and NFA groups after 35 and 70 days, respectively. The optimum concentration of additional NFHA and NFA for maximal fluoride release, according to the authors, was 25 weight percent, which virtually quadrupled fluoride release after 70 days when compared to the control group. In another study, Shankar et al. (2020) investigated the impact of nano-hydroxyapatite (Nano-HA) in orthodontic banding cement in vivo. After 60 days, the methylene blue dye penetration technique was used to measure microleakage under orthodontic bands. Compared to those cemented with Nano-HA-modified glass ionomer cement, orthodontic bands cemented with regular glass ionomer cement had the greatest microleakage ratings (Heravi et al., 2019).

2.3. Nanofillers or NPs (TiO_2, silver), being incorporated into orthodontic adhesives

The retention capacity of cariogenic streptococci was higher in orthodontic adhesives than in bracket components (Lim et al., 2008). Surface roughness may be reduced in nano-filled adhesives with smaller and more evenly dispersed filler particles, compromising bacterial adhesion. Once nano-filled adhesives were utilized for bonding orthodontic brackets in prior short-term, 24-hour in-vitro researches, shear bond strength was comparable or lower but still allowable (Bishara et al., 2007; Chalipa et al., 2013). Nanofillers lowered the adhesive's surface roughness compared to customary orthodontic adhesives (Uysal et al., 2010; Pai et al., 2012). When silver nanoparticles were added to the mixture, nevertheless, this was not the case (Jasso-Ruiz et al., 2020). However, the long-term influence of nano-filled adhesives on enamel demineralization prevention throughout orthodontic therapy has still to be studied. Silver has long been known for its antibacterial features against cariogenic Streptococcus mutans, antibiotic-resistant strains as some viruses, protozoa, and fungi, as well as Gram-negative/ affirmative bacteria (Degrazia et al., 2016; Dutra-Correa et al., 2018). Antibacterial properties were demonstrated against oral streptococci using resin composites containing silver-implanted fillers. Gonçalves et al. (2020) investigated the effects of various silver NP levels in an empirical composite adhesive comprising silica nanofillers. According to this paper, adding silver NPs to orthodontic adhesive dramatically reduced cariogenic streptococci adherence compared to typical adhesives without sacrificing physical characteristics. Sodagar et al. (2017) showed that adding TiO_2 NPs (1% w/w) to an orthodontic glue improved its antibacterial capabilities without affecting its physical characteristics. Adhesives containing TiO_2 NPs exhibited considerably greater antibacterial activity during the first 30 days, which remained consistent. When orthodontic adhesives containing additional TiO_2 NPs were employed, a bacterial colony count indicated no substantial changes in bacterial growth instantly or about four weeks (30 days) after the trial began.

2.4. Acrylic orthodontic materials with silver, SiO_2, or TiO_2 nanoparticles

Removable orthodontic appliances include expanders, retainers, and functional appliances. These devices are often made with cold-cure acrylic resins. Resins are mostly composed of polymethyl methacrylate (PMMA) (Rantala et al., 2003; Zafar, 2020; Poonpiriya et al., 2021). Microbial plaque attaches to acrylic resin appliances with a larger adhesion surface than normal teeth, which can contribute to cariogenic oral flora growth (Arab et al., 2021). Candida Albicans (CA) [Candida-induced stomatitis] is an erythematous infection (red areas) of the oral mucosa that can develop beneath retainers, detachable appliances, or dentures (denture stomatitis) (Ribeiro et al., 2006; Höfling et al., 2010; Rebolledo-Cobos and Sánchez-Molina, 2018; Sugio et al., 2020). Oral Candida carriage was identified in 25-75 percent of research groups, indicating that CA is an opportunistic infection. It has been hypothesized that the existence of an acrylic detachable device is linked to Candida carrier status and low salivary pH levels (Majima et al., 2014). Prior to treatment, the proportion of CA carriers was lowered to 14% in one research. Similarly, as compared to tooth-borne orthodontic appliances, the tooth-tissue-borne orthodontic equipment induced greater CA proliferation (Javed et al., 2014). The rise in Candida proliferation in detachable instruments wearers may be related to safety from mechanical and natural saliva and defense system removal (Arita et al., 2005). Managing the spread of CA under detachable acrylic equipment may help to avoid orthodontic stomatitis. It's critical to detect new ways to treat CA that have developed a resistance to antifungal medicines. Antimicrobial characteristics of NP-incorporated acrylic polymers and their usage in detachable instruments are yet in the preliminary phases of research, and in-vitro models are being used (Sultan et al., 2019; Sugio et al., 2020). After adding SiO_2 (1%) and TiO_2 (0.5%) NPs to a PMMA acrylic resin, Gad et al. (2020) investigated how the flexural strength changed. The concentration of NPs in acrylic resin has an adverse effect on the final product's flexural strength. When silver nanoparticles were introduced to two PMMA resins' acrylic liquid, at various silver NP concentrations, a varied influence on flexural strength was observed. Another research found that samples of PMMA with silver NP reduced CA adhesion significantly and exhibited biocompatibility, as they had no effect on proliferation/cell metabolism and did not trigger genotoxic harm to cells (to investigate this, researchers utilized mouse fibroblasts and human lymphocytes). PMMA samples with silver NPs had lower flexural strength than PMMA samples without NPs once again. The restrictions of the studies stated before must be acknowledged. Some researchers didn't test the antibacterial or safety properties of the NP- combined acrylic polymers, while others only tested biocompatibility for 24-72 hours. The citotoxity and immunological reaction may be affected by the size of the NP. Smaller silver NPs of 3 nm, for example, have been shown to be more cytotoxic than bigger silver NPs of 25 nm. When assessing the cytotoxicity of any NP-incorporated substance, this aspect must be considered.

3. Conclusion

While the application of nanoparticles in orthodontics may open up new options, the published research only looked at antibacterial or physical characteristics for a limited period of time, such as 24 hours to a few weeks. It's also important to acknowledge the restrictions of studies conducted mostly in vitro. Knowledge on the long-term functionality of orthodontic material created using this way is scarce. It requires investigation, as do any safety problems (toxicity) associated with the NP sizes.

References

AGNIHOTRI, R., GAUR, S. and ALBIN, S., 2020. Nanometals in dentistry: applications and toxicological implications: a systematic review. *Biological Trace Element Research*, vol. 197, no. 1, pp. 70-88. http://dx.doi.org/10.1007/s12011-019-01986-y. PMid:31782063.

ANSARIFARD, E., ZARESHAHRABADI, Z., SARAFRAZ, N. and ZOMORODIAN, K., 2021. Evaluation of antimicrobial and antibiofilm activities of copper oxide nanoparticles within soft denture liners against oral pathogens. *Bioinorganic Chemistry and Applications*, vol. 2021, pp. 9939275. http://dx.doi.org/10.1155/2021/9939275. PMid:34149837.

ARAB, S., BAHADOR, A., SODAGAR, A., POURHAJIBAGHER, M., AKHAVAN, A., HAFITH, A.N. and PORNAMAZEH, T., 2021. Antimicrobial properties of acrylic resin incorporated with propolis nanoparticles. *Frontiers in Dentistry*, vol. 18, pp. 18. http://dx.doi.org/10.18502/fid.v18i29.6939.

ARITA, M., NAGAYOSHI, M., FUKUIZUMI, T., OKINAGA, T., MASUMI, S., MORIKAWA, M., KAKINOKI, Y. and NISHIHARA, T., 2005. Microbicidal efficacy of ozonated water against *Candida albicans* adhering to acrylic denture plates. *Oral Microbiology and Immunology*, vol. 20, no. 4, pp. 206-210. http://dx.doi.org/10.1111/j.1399-302X.2005.00213.x. PMid:15943763.

BĄCELA, J., ŁABOWSKA, M.B., DETYNA, J., ZIĘTY, A. and MICHALAK, I., 2020. Functional coatings for orthodontic archwires: a review. *Materials*, vol. 13, no. 15, pp. 3257. http://dx.doi.org/10.3390/ma13153257. PMid:32707959.

BAPAT, R.A., JOSHI, C.P., BAPAT, P., CHAUBAL, T.V., PANDURANGAPPA, R., JNANENDRAPPA, N., GORAIN, B., KHURANA, S. and KESHARWANI, P., 2019. The use of nanoparticles as biomaterials in dentistry. *Drug Discovery Today*, vol. 24, no. 1, pp. 85-98. http://dx.doi.org/10.1016/j.drudis.2018.08.012. PMid:30176358.

BEHNAZ, M., DALAIE, K., MIRMOHAMMADSADEGHI, H., SALEHI, H., RAKHSHAN, V. and ASLANI, F., 2018. Shear bond strength and adhesive remnant index of orthodontic brackets bonded to enamel using adhesive systems mixed with TiO_2 nanoparticles. *Dental Press Journal of Orthodontics*, vol. 23, no. 4, pp. 43.e1. http://dx.doi.org/10.1590/2177-6709.23.4.43.e1-7.onl. PMid:30304159.

BISHARA, S.E., AJLOUNI, R., SOLIMAN, M.M., OONSOMBAT, C., LAFFOON, J.F. and WARREN, J., 2007. Evaluation of a new nano-filled restorative material for bonding orthodontic brackets. *World Journal of Orthodontics*, vol. 8, no. 1, pp. 8 PMid:17373220.

BORZABADI-FARAHANI, A., BORZABADI, E. and LYNCH, E., 2014. Nanoparticles in orthodontics, a review of antimicrobial and anti-caries applications. *Acta Odontologica Scandinavica*, vol. 72, no. 6, pp. 413-417. http://dx.doi.org/10.3109/00016357.2013.859728. PMid:24325608.

CAO, B., WANG, Y., LI, N., LIU, B. and ZHANG, Y., 2013. Preparation of an orthodontic bracket coated with an nitrogen-doped TiO2-xNy thin film and examination of its antimicrobial performance. *Dental Materials Journal*, vol. 32, no. 2, pp. 311-316. http://dx.doi.org/10.4012/dmj.2012-155. PMid:23538768.

CHALIPA, J., AKHONDI, M.S.A., ARAB, S., KHARRAZIFARD, M.J. and AHMADYAR, M., 2013. Evaluation of shear bond strength of orthodontic brackets bonded with nano-filled composites. *Journal of Dentistry*, vol. 10, no. 5, pp. 461-465. PMid:24910655.

CHEN, X. and SELLONI, A., 2014. Introduction: titanium dioxide (TiO_2) nanomaterials. *Chemical Reviews*, vol. 114, no. 19, pp. 9281-9282. http://dx.doi.org/10.1021/cr500422r. PMid:25294394.

CHEN, X., DALIRI, E.B.-M., KIM, N., KIM, J.-R., YOO, D. and OH, D.-H., 2020. Microbial etiology and prevention of dental caries: exploiting natural products to inhibit cariogenic biofilms. *Pathogens*, vol. 9, no. 7, pp. 569. http://dx.doi.org/10.3390/pathogens9070569. PMid:32674310.

CUPPINI, M., LEITUNE, V.C.B., SOUZA, M., ALVES, A.K., SAMUEL, S.M.W. and COLLARES, F.M., 2019. In vitro evaluation of visible light-activated titanium dioxide photocatalysis for in-office dental bleaching. *Dental Materials Journal*, vol. 38, no. 1, pp. 68-74. http://dx.doi.org/10.4012/dmj.2017-199. PMid:30449826.

DEGRAZIA, F.W., LEITUNE, V.C.B., GARCIA, I.M., ARTHUR, R.A., SAMUEL, S.M.W. and COLLARES, F.M., 2016. Effect of silver nanoparticles on the physicochemical and antimicrobial properties of an orthodontic adhesive. *Journal of Applied Oral Science*, vol. 24, no. 4, pp. 404-410. http://dx.doi.org/10.1590/1678-775720160154. PMid:27556213.

DUTRA-CORREA, M., LEITE, A.A., DE CARA, S.P., DINIZ, I.M., MARQUES, M.M., SUFFREDINI, I.B., FERNANDES, M.S., TOMA, S.H., ARAKI, K. and MEDEIROS, I.S., 2018. Antibacterial effects and cytotoxicity of an adhesive containing low concentration of silver nanoparticles. *Journal of Dentistry*, vol. 77, pp. 66-71. http://dx.doi.org/10.1016/j.jdent.2018.07.010. PMid:30009857.

ENAN, E.T. and HAMMAD, S.M., 2013. Microleakage under orthodontic bands cemented with nano-hydroxyapatite-modified glass ionomer. *The Angle Orthodontist*, vol. 83, no. 6, pp. 981-986. http://dx.doi.org/10.2319/022013-147.1. PMid:23745977.

GAD, M.M.A., ABUALSAUD, R., AL-THOBITY, A.M., ALMASKIN, D.F., ALZAHER, Z.A., ABUSHOWMI, T.H., QAW, M.S., AKHTAR, S. and AL-HARBI, F.A., 2020. Effect of SiO_2 nanoparticles addition on the flexural strength of repaired acrylic denture base. *European Journal of Dentistry*, vol. 14, no. 1, pp. 19-23. http://dx.doi.org/10.1055/s-0039-1701076. PMid:31955401.

GEORGE, A.M., NAMBI, N., SHRINIVAASAN, N.R., DHAYANANTH, L.X. and CHAJALLANI, V.G., SHRINIVAASAN, N.R., DHAYANANTH, L.X., CHAJALLANI, V.G. and GEORGE, A.M., 2016. Renaissance in orthodontics: nanotechnology. *International Journal of Orthodontic Rehabilitation*, vol. 7, no. 4, pp. 139. http://dx.doi.org/10.4103/2349-5243.197461.

GODOY-BEZERRA, J., VIEIRA, S., OLIVEIRA, J.H.G. and LARA, F., 2006. Shear bond strength of resin-modified glass ionomer cement with saliva present and different enamel pretreatments. *The Angle Orthodontist*, vol. 76, no. 3, pp. 470-474. PMid:16637729.

GONÇALVES, I.S., VIALE, A.B., SORMANI, N.N., PIZZOL, K.E.D.C., ARAUJO-NOBRE, A.R., OLIVEIRA, P.C.S., BARUD, H.G.O., ANTONIO, S.G. and BARUD, H.S., 2020. Antimicrobial orthodontic wires coated with silver nanoparticles. *Brazilian Archives of Biology and Technology*, vol. 63, pp. e20190339. http://dx.doi.org/10.1590/1678-4324-2020190339.

GORTON, J. and FEATHERSTONE, J.D., 2003. In vivo inhibition of demineralization around orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 123, no. 1, pp. 10-14. http://dx.doi.org/10.1067/mod.2003.47. PMid:12532056.

HERAVI, F., BAGHERI, H. and RANGRAZI, A., 2019. Evaluation of microleakage of orthodontic bands cemented with CPP-ACP-modified glass ionomer cement. *Journal of Advanced Oral Research*, vol. 10, no. 2, pp. 128-131. http://dx.doi.org/10.1177/2320206819864470.

HÖFLING, J.F., ANIBAL, P.C., OBANDO-PEREDA, G.A., PEIXOTO, I.A.T., FURLETTI, V.F., FOGLIO, M.A. and GONÇALVES, R.B., 2010. Antimicrobial potential of some plant extracts against Candida species. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 70, no. 4, pp. 1065-1068. http://dx.doi.org/10.1590/S1519-69842010000500022. PMid:21180915.

JASSO-RUIZ, I., VELAZQUEZ-ENRIQUEZ, U., SCOUGALL-VILCHIS, R.J., MORALES-LUCKIE, R.A., SAWADA, T. and YAMAGUCHI, R., 2020. Silver nanoparticles in orthodontics, a new alternative in bacterial inhibition: in vitro study. *Progress in Orthodontics*, vol. 21, no. 1, pp. 24. http://dx.doi.org/10.1186/s40510-020-00324-6. PMid:32803386.

JAVED, F., TENENBAUM, H.C., NOGUEIRA-FILHO, G., NOOH, N., TAIYEB ALI, T.B., SAMARANAYAKE, L.P. and AL-HEZAIMI, K., 2014. Oral Candida carriage and species prevalence amongst habitual gutka-chewers and non-chewers. *International Wound Journal*, vol. 11, no. 1, pp. 79-84. http://dx.doi.org/10.1111/j.1742-481X.2012.01070.x. PMid:22883719.

KAMIYA, R.U., TAIETE, T. and GONÇALVES, R.B., 2011. Mutacins of *Streptococcus mutans*. *Brazilian Journal of Microbiology*, vol. 42, no. 4, pp. 1248-1258. http://dx.doi.org/10.1590/S1517-83822011000400001. PMid:24031748.

KIDD, E.A.M. and FEJERSKOV, O., 2004. What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. *Journal of Dental Research*, vol. 83, no. 1, suppl., pp. 35-38. http://dx.doi.org/10.1177/154405910408301s07. PMid:15286119.

LEMOS, J.A., PALMER, S.R., ZENG, L., WEN, Z.T., KAJFASZ, J.K., FREIRES, I.A., ABRANCHES, J. and BRADY, L.J., 2019. The biology of Streptococcus mutans. *Microbiology Spectrum*, vol. 7, no. 1. http://dx.doi.org/10.1128/microbiolspec.GPP3-0051-2018. PMid:30657107.

LIM, B.-S., LEE, S.-J., LEE, J.-W. and AHN, S.-J., 2008. Quantitative analysis of adhesion of cariogenic streptococci to orthodontic raw materials. *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 133, no. 6, pp. 882-888. http://dx.doi.org/10.1016/j.ajodo.2006.07.027. PMid:18538253.

MAJIMA, T., ITO-KUWA, S., NAGATOMI, R. and NAKAMURA, K., 2014. Study of the oral carriage of Candida sp. in dental students and staff: identification of Candida sp. and background survey. *Oral Science International*, vol. 11, no. 1, pp. 30-34. http://dx.doi.org/10.1016/S1348-8643(13)00029-3.

MALIK, S., AHMED, M.A., CHOUDHRY, Z., MUGHAL, N., AMIN, M. and LONE, M.A., 2018. Fluoride release from glass ionomer cement containing fluoroapatite and hydroxyapatite. *Journal of Ayub Medical College, Abbottabad*, vol. 30, no. 2, pp. 198-202. PMid:29938418.

MARUO, I.T., GODOY-BEZERRA, J., SAGA, A.Y., TANAKA, O.M., MARUO, H. and CAMARGO, E.S., 2010. Effect of etching and light-curing time on the shear bond strength of a resin-modified glass ionomer cement. *Brazilian Dental Journal*, vol. 21, no. 6, pp. 533-537. http://dx.doi.org/10.1590/S0103-64402010000600009. PMid:21271044.

MELO, M.A.S., CHENG, L., WEIR, M.D., HSIA, R.C., RODRIGUES, L.K. and XU, H.H., 2013. Novel dental adhesive containing antibacterial agents and calcium phosphate nanoparticles. *Journal of Biomedical Materials Research. Part B, Applied Biomaterials*, vol. 101, no. 4, pp. 620-629. http://dx.doi.org/10.1002/jbm.b.32864. PMid:23281264.

MITWALLI, H., ALSAHAFI, R., ALBESHIR, E.G., DAI, Q., SUN, J., OATES, T.W., MELO, M.A.S., XU, H.H. and WEIR, M.D., 2021. Novel nano calcium fluoride remineralizing and antibacterial dental composites. *Journal of Dentistry*, vol. 113, pp. 103789. http://dx.doi.org/10.1016/j.jdent.2021.103789. PMid:34455017.

MOBEEN, N., KISHORE, S., GANDHI, R., DURAISAMY, S. and RAVI, K., 2021. Biosafety of nanoparticles used in orthodontics: a literature review. *Journal of Evolution of Medical and Dental Sciences*, vol. 10, no. 32, pp. 2658-2665. http://dx.doi.org/10.14260/jemds/2021/543.

MORAIS, D.R., MORESCA, A.H.K., LOSSO, E.M., MORO, A., MORESCA, R.C. and CORRER, G.M., 2015. Shear bond strength of brackets bonded with nanofilled flowable resins. *Revista Sul-Brasileira de Odontologia*, vol. 12, no. 1, pp. 8-13.

MORITZ, M. and GESZKE-MORITZ, M., 2013. The newest achievements in synthesis, immobilization and practical applications of antibacterial nanoparticles. *Chemical Engineering Journal*, vol. 228, pp. 596-613. http://dx.doi.org/10.1016/j.cej.2013.05.046.

NAYAK, A.K., MAZUMDER, S., ARA, T.J., ANSARI, M.T. and HASNAIN, M.S. 2019. Calcium fluoride-based dental nanocomposites. In: A.M. ASIRI, INAMUDDIN and A. MOHAMMAD, eds. *Applications of nanocomposite materials in dentistry*. Duxford: Woodhead Publishing, pp. 27-45.

NAYAK, R.S., VALECHA, S., PASHA, A., MAMATHA, J., KHANNA, B. and SHAFIUDDIN, B., 2015. A comparison of shear bond strength of new nanofilled composite and nano-ionomer restorative materials with traditional adhesive material for orthodontic bracket bonding: an in vitro study. *Journal of International Oral Health*, vol. 7, no. 10, pp. 70.

PAI, S.S., NAGENDRA, A., PAI, V.S., NEELIMA, K., VISHWANATH, A.E., VINOD, P., KUMAR, S.A. and TUBAKI, R.R., 2012. Evaluation of a new nano-filled bonding agent for bonding orthodontic brackets as compared to a conventional bonding agent: an in vitro study. *The Journal of Indian Orthodontic Society*, vol. 46, no. 4, suppl. 2, pp. 239-333. http://dx.doi.org/10.1177/0974909820120607S.

PASCOTTO, R.C., NAVARRO, M.F.L., CAPELOZZA FILHO, L. and CURY, J.A., 2004. In vivo effect of a resin-modified glass ionomer cement on enamel demineralization around orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 125, no. 1, pp. 36-41. http://dx.doi.org/10.1016/S0889-5406(03)00571-7. PMid:14718877.

PEREIRA, T.B.J., JANSEN, W.C., PITHON, M.M., SOUKI, B.Q., TANAKA, O.M. and OLIVEIRA, D.D., 2013. Effects of enamel deproteinization on bracket bonding with conventional and resin-modified glass ionomer cements. *European Journal of Orthodontics*, vol. 35, no. 4, pp. 442-446. http://dx.doi.org/10.1093/ejo/cjs006. PMid:22379131.

POONPIRIYA, T., SAWAENGKIT, P., CHURNJITAPIROM, P. and THAWEBOON, S., 2021. Water sorption and solubility of vanillin-incorporated self-curing orthodontic polymethylmethacrylate resin. *Materials Science Forum*, vol. 1020, pp. 187-191. http://dx.doi.org/10.4028/www.scientific.net/MSF.1020.187.

RANTALA, L.I., LASTUMÄKI, T.M., PELTOMÄKI, T. and VALLITTU, P.K., 2003. Fatigue resistance of removable orthodontic appliance reinforced with glass fibre weave. *Journal of Oral Rehabilitation*, vol. 30, no. 5, pp. 501-506. http://dx.doi.org/10.1046/j.1365-2842.2003.01108.x. PMid:12752930.

REBOLLEDO-COBOS, M. and SÁNCHEZ-MOLINA, M., 2018. Oral pathogen Candida in patients under antineoplastic therapies. *Revista de la Facultad de Odontología Universidad de Antioquia*, vol. 30, no. 1, pp. 92-104.

RIBEIRO, E.L., SCROFERNEKER, M.L., CAVALHAES, M.S., CAMPOS, C.C., NAGATO, G.M., SOUZA, N.A., FERREIRA, W.M., CARDOSO, C.G., DIAS, S.M.S., PIMENTA, F.C. and TOLEDO, O.A., 2006. Phenotypic aspects of oral strains of Candida albicans in children with down's syndrome. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 66, no. 3, pp. 939-944. http://dx.doi.org/10.1590/S1519-69842006000500020. PMid:17119842.

ROIG-VANACLOCHA, A., SOLÁ-RUIZ, M.F., ROMÁN-RODRÍGUEZ, J.L., AMENGUAL-LORENZO, J., ALONSO PÉREZ-BARQUERO, J. and AGUSTÍN-PANADERO, R., 2020. Dental treatment of white spots and a description of the technique and digital quantification of the loss of enamel volume. *Applied Sciences*, vol. 10, no. 12, pp. 4369. http://dx.doi.org/10.3390/app10124369.

SALEHI, P., BABANOURI, N., ROEIN-PEIKAR, M. and ZARE, F., 2018. Long-term antimicrobial assessment of orthodontic brackets coated with nitrogen-doped titanium dioxide against Streptococcus mutans. *Progress in Orthodontics*, vol. 19, no. 1, pp. 1-6. http://dx.doi.org/10.1186/s40510-018-0236-y. PMid:30221309.

SCHRAND, A.M., RAHMAN, M.F., HUSSAIN, S.M., SCHLAGER, J.J., SMITH, D.A. and SYED, A.F., 2010. Metal-based nanoparticles and their toxicity assessment. *Wiley Interdisciplinary Reviews. Nanomedicine and Nanobiotechnology*, vol. 2, no. 5, pp. 544-568. http://dx.doi.org/10.1002/wnan.103. PMid:20681021.

SHANKAR, P., VENKATESAN, R., SENTHIL, D., TROPHIMUS, J., ARTHILAKSHMI, C.U. and PRINCY, P., 2020. Microleakage patterns of glass ionomer cement at cement-band and cement-enamel interfaces in primary teeth. *Indian Journal of Dental Research*, vol. 31, no. 2, pp. 291-296. http://dx.doi.org/10.4103/ijdr.IJDR_850_19. PMid:32436911.

SHARAFEDDIN, F., ALAVI, A.A., SIABANI, S. and SAFARI, M., 2020. Comparison of shear bond strength of three types of glass ionomer cements containing hydroxyapatite nanoparticles to deep and superficial dentin. *Journal of Dentistry*, vol. 21, no. 2, pp. 132-140. PMid:32582829.

SHKODENKO, L., KASSIROV, I. and KOSHEL, E., 2020. Metal oxide nanoparticles against bacterial biofilms: perspectives and limitations. *Microorganisms*, vol. 8, no. 10, pp. 1545. http://dx.doi.org/10.3390/microorganisms8101545. PMid:33036373.

SODAGAR, A., AKHOUNDI, M.S.A., BAHADOR, A., JALALI, Y.F., BEHZADI, Z., ELHAMINEJAD, F. and MIRHASHEMI, A.H., 2017. Effect of TiO_2 nanoparticles incorporation on antibacterial properties and shear bond strength of dental composite used in Orthodontics. *Dental Press Journal of Orthodontics*, vol. 22, no. 5, pp. 67-74. http://dx.doi.org/10.1590/2177-6709.22.5.067-074.oar. PMid:29160346.

SONG, W. and GE, S., 2019. Application of antimicrobial nanoparticles in dentistry. *Molecules*, vol. 24, no. 6, pp. 1033. http://dx.doi.org/10.3390/molecules24061033. PMid:30875929.

SUDJALIM, T.R., WOODS, M.G., MANTON, D.J. and REYNOLDS, E.C., 2007. Prevention of demineralization around orthodontic brackets in vitro. *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 131, no. 6, pp. 705.e1. http://dx.doi.org/10.1016/j.ajodo.2006.09.043. PMid:17561043.

SUGIO, C.Y.C., GARCIA, A.A.M.N., ALBACH, T., MORAES, G.S., BONFANTE, E.A., URBAN, V.M. and NEPPELENBROEK, K.H., 2020. Candida-associated denture stomatitis and murine models: what is the importance and scientific evidence? *Journal of Fungi*, vol. 6, no. 2, pp. 70. http://dx.doi.org/10.3390/jof6020070. PMid:32456172.

SULTAN, A.S., RIZK, A.M., VILA, T., JI, Y., MASRI, R. and JABRA-RIZK, M.A., 2019. Digital design of a universal rat intraoral device for therapeutic evaluation of a topical formulation against Candida-associated denture stomatitis. *Infection and Immunity*, vol. 87, no. 12, pp. e00617-e00619. http://dx.doi.org/10.1128/IAI.00617-19. PMid:31527130.

TANDRA, E., WAHYUNINGTYAS, E. and SUGIATNO, E., 2018. The effect of nanoparticles TiO_2 on the flexural strength of acrylic resin denture plate. *Padjadjaran Journal of Dentistry*, vol. 30, no. 1, pp. 35-40. http://dx.doi.org/10.24198/pjd.vol30no1.16110.

TEUBL, B.J., SCHIMPEL, C., LEITINGER, G., BAUER, B., FRÖHLICH, E., ZIMMER, A. and ROBLEGG, E., 2015. Interactions between nano-TiO2 and the oral cavity: impact of nanomaterial surface hydrophilicity/hydrophobicity. *Journal of Hazardous Materials*, vol. 286, pp. 298. http://dx.doi.org/10.1016/j.jhazmat.2014.12.064. PMid:25590824.

TOODEHZAEIM, M.H., ZANDI, H., MESHKANI, H., and FIROUZABADI, A.H., 2018. The effect of CuO nanoparticles on antimicrobial effects and shear bond strength of orthodontic adhesives. *Journal of Dentistry*, vol. 19, no. 1, pp. 1-18.

UYSAL, T., YAGCI, A., UYSAL, B. and AKDOGAN, G., 2010. Are nano-composites and nano-ionomers suitable for orthodontic bracket bonding? *European Journal of Orthodontics*, vol. 32, no. 1, pp. 78-82. http://dx.doi.org/10.1093/ejo/cjp012. PMid:19401356.

WOLD, A., 1993. Photocatalytic properties of titanium dioxide (TiO2). *Chemistry of Materials*, vol. 5, no. 3, pp. 280-283. http://dx.doi.org/10.1021/cm00027a008.

YASEEN, R., KOTP, Y.H. and EISSA, D., 2020. The impact of production of silver nanoparticles using soil fungi and its applications for reducing irrigation water salinity. *Journal of Water and Land Development*, no. 46, pp. 216-228. http://dx.doi.org/10.24425/jwld.2020.134216.

ZAFAR, M.S., 2020. Prosthodontic applications of polymethyl methacrylate (PMMA): an update. *Polymers*, vol. 12, no. 10, pp. 2299. http://dx.doi.org/10.3390/polym12102299. PMid:33049984.