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Review

Improvement of Quality of Life through Nanoparticles in Restorative Dentistry

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Abstract

Dental methods aimed at dental rehabilitation, regional anesthesia, orthodontic realigning, permanent hypersensitivity treatment, covalent bonding diamondized enamel, dental health preservation using mechanical dentifrobots, and the formation of artificial bone and teeth are among the possible uses of nanotools in dentistry. The evaluation and treatment of problems affecting the teeth and their surrounding tissues are the focus of restorative dentistry. For the restoration of tooth function and the repair and replacement of damaged tooth structures as well as better aesthetics, advanced procedures are required. In the past few years, resin-based dental restorative materials have made significant progress. Dental composite resin's mechanical performance, minimal polymerization contraction, strong wear resistance, and surface hardness can all be considerably improved by adding nanoparticles to the matrix. To date, nanocomposites for the repair of tooth structure have made one of the most significant contributions to restorative and cosmetic dentistry. Nanocomposites' characteristics aid in minimizing polymerization loss. Their microhardness is higher than that of already employed posterior resin-based composites, and the improved polishability properties in turn result in a smoother surface with better shade qualities. Nanocomposites have a number of benefits, including reduced weight, excellent thermal and electrical properties, antimicrobial activity, and the ability to remineralize dental defects. The other nanotools used in restorative dentistry are nanoadhesives, nanoionomers and nano-endodontic sealants. Nanoadhesives protect against failure of a restoration from bacterial invasion occurs due to spaces between restorative material and preparation margins. Nanoionomers chemically adhere to the surface of the tooth and offer advantages of enhanced bond strength, chemical stability, and insoluble nature. Nano endodontic sealers have the advantage of sealing better than conventional sealers and employing nanoparticles effectively acts as an antibacterial agent. Due to its potential uses and advantages, there is a growing demand for and interest in nano-based dental materials.

Keywords: *nanotechnology, nanocomposites, oral health related quality of life, nanoparticles, restorative dentistry*

Introduction

Since its inception, the incorporation of nanotechnology into "dental interventions" has significantly advanced the identification, prevention, and management of a broad range of dental conditions (1). Dental methods aimed at dental rehabilitation, regional anesthesia, orthodontic realigning, permanent hypersensitivity treatment, covalent bonding diamondized enamel, dental health preservation using mechanical dentifrobots, and the formation of artificial bone and teeth are among the possible uses of nanotools in dentistry (2). There is a growing consensus that using nanotechnology in dental medicine will greatly help in diagnosing, preventing, and treating oral health problems.

The primary strategies that aid in the practical application of nanotools include a bottom-up method and a top-down approach. A bottom-up approach entails organizing simpler elements into more intricate ones. It focuses on the use of miniature nanorobots that can be controlled to perform a variety of manual tasks, including administering local anesthesia, honing the enamel surface with diamondized covalent bonding, treating tooth sensitivity, improving dental longevity and aesthetics, and using photosensitizers like quantum dots to strike particular targets (3). The second approach is a top-down approach, which encourages the creation of smaller-dimensional nanostructures from bigger components. Nanoscaled solutions, needles, fillers, composites, and bone replacement materials are typically used in this procedure (4). AdperTM single bond plus is a type of a dentin adhering nanosolution with a single step application process (5). In order to reduce tissue injury, suture needles with nanosized stainless steel crystals, such as Sandvik Bioline RK 91TM needles, have been created (6). The saliva can be examined by the biochemical sensing devices in salivary diagnostics, which also uses the top-down technique of nanotechnology. An example of an automated and integrated system to identify the targeted protein and nucleic acid in saliva is the oral fluid nanosensor test (OFNASET) (7, 8).

One of the most popular uses of nanotechnology is in oral medicine, which has the potential to increase people's quality of life through enhancing dental health. Years of controversy have surrounded the safety of using nanoparticles on people, however research on these materials has shown that there are actually more benefits to using them than drawbacks (9). A scale between 1 and 100 nm is used in nanoscience research (10). Environmentally friendly nanofillers using "green chemistry" have also been developed as a result of research in nano-biotechnology (11, 12). Due to their minute size, high density, and distinctive physicochemical characteristics, nanomaterials have received a lot of interest for usage in a variety of dentistry procedures (13-15). Finding composites that can restore the original dental appearance while simulating missing dentinal tissue is a challenge that most dentists face. The creation of sophisticated nanomaterials using a bio-mimetic approach based on nanotechnology has been seen as a more recent method (16, 17). Biofilms on the surfaces of teeth in the mouth are broken down or prevented from forming by oral antibacterial substances. The antibacterial capabilities of biomaterials may be enhanced by adding components like silver, gold, or titanium nanoparticles (18). Metallic nanoparticles (Metal NPs) have a wide surface area, which expands their antimicrobial potential. Moreover, these materials can also improve the strength and endurance of mechanical characteristics (19). Dental nanocomposites may contain inorganic nanoparticles made predominantly of metal NPs or metal oxide NPs as fillers (20, 21). The formation of colonies along the margins between the tooth surface and restorative material by a pathogenic microorganism like Streptococcus mutans results in tooth decay. Such antibacterial components can greatly increase the effectiveness of dental restorations (22-24).

Methodology

This study is based on a comprehensive literature search conducted on October 2, 2022, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the information about improvement in the quality of life through nanoparticles used in restorative dentistry. There were no restrictions on date, language, participant age, or type of publication.

Discussion

Nanomaterials have undergone impressive development in recent years, taking them from a theoretical base to practical use. There are now numerous uses for nanomaterials in various subspecialties of dentistry (25-

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32). The diversity of goods available for different dental applications is anticipated to significantly rise in the coming years as a result of ongoing research into the development of novel nano-products.

The evaluation and treatment of problems affecting the teeth and their surrounding tissues are the focus of restorative dentistry. For the restoration of tooth function and the repair and replacement of damaged tooth structures as well as better aesthetics, advanced procedures are required (33). In the past few years, resin-based dental restorative materials have made significant progress. Dental composite resin's mechanical performance, minimal polymerization contraction, strong wear resistance, and surface hardness can all be considerably improved by adding nanoparticles to the matrix (34, 35). According to a recently published study, adding fluoro-aluminosilicate glass nanoparticles to GIC enhanced its mechanical characteristics and aesthetics (35). Nanoionomers (KetacTM Nano; 3M ESPE) have recently been authorized for use in therapeutic settings (1). The four categories of nanomaterials include polymers, metals, composites, and ceramics (36).

Nanocomposites

To date, nanocomposites for the repair of tooth structure have made one of the most significant contributions to restorative and cosmetic dentistry (37). Nanoscale particles and matrix material make up nanocomposites. These composites, which differ from the present microfilled and hybrid resin-based composites in terms of toughness and aesthetics, are defined by filler-particle diameters of less than 100 nm. The synthesis process has an impact on the substance's characteristics. The nanocomposite's matrix can be polymeric, metallic, or ceramic (38, 39). Nanocomposites' characteristics aid in minimizing polymerization loss (40). Silver and zinc oxide nanoparticles, as well as composites, have demonstrated to have effective antibacterial properties against Lactobacilli spp. and Streptococcus mutans (41). Nanoscopic carbon-based fillers, layered clay, pervious and hollowed particles, cellulose, and particles containing metallic ions are all components of nanocomposites. Nanotubes and graphene are two examples of the carbon-based fillers. In situ polymerizing, melt mixing, and solution blending are the three processes used to create polymer nanocomposites (42).

Fillers smaller than 100 nm are frequently used in nanotechnology-based composites as Estelite® Sigma and FiltekTM Supreme Plus from Tokuyama America, Inc. and 3M ESPE, respectively. Better dispersion and a larger interfacial area between the matrix and filler should be the results of using filler particle sizes that are gradually smaller. This would boost the finished restoration's flexural strength, surface microhardness, and polishability (43). Their microhardness is higher than that of already employed posterior resin-based composites, and the improved polishability properties in turn result in a smoother surface with better shade qualities. Nanofilled restoratives are currently being used with nanocluster particles as tiny as 2-20 nm (32). These smaller particles allow for the maximization of features including optical qualities, which may have an impact on aesthetic dentistry (32) [translucent shades have fillers of 5–20 nm]. Particles can be separated from the composite matrix by polishing and abrasions brought on by function. However, polishing and functional abrasions would only permit weakly connected nanoclusters to dissociate from the nanocomposites; as a result, a well-polished repair surface would continue to be smooth for a considerable amount of time. Additionally, the particles that are removed from the nanocomposites' surfaces and cause flaws to emerge during abrasion are nanoscale in size and smaller than the wavelength of light. Nanocomposites have better optical character because particles with a wavelength of visible light (0.4 to 0.8 m) do not reflect light (32). Because the fillers in nanocomposites are smaller than the wavelength of light, they are more translucent and enable the creation of more aesthetic restorations with a wide variety of color possibilities (4). Bigger particles in the 0.4-5 micrometer range can be found in nanohybrids (44). Since they offer good strength and stability, nanohybrid composites containing nanoparticles can be incorporated in ceramic laminates (45, 46). Nanocomposites have a number of benefits, including reduced weight, excellent thermal and electrical properties, antimicrobial activity, and the ability to remineralize dental defects (47, 48).

Adhesives

Dental adhesives are resinous monomeric substances in solvents that facilitates substrate interaction (49). The failure of a restoration occurs when subsequent bacterial invasion occurs; the adhesives' antimicrobial properties aid to lessen the bacterial impacts (50). The surface tension of adhesives is increased by the nanoparticles (51). The addition of unstructured nanoscaled calcium phosphate and silver particles in the adhesives improved the material's bond strength and had a positive antimicrobial action (50). The adhesives' microshear bond strength was demonstrated by the aluminum oxide

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addition (52). The microshear binding strength of the adhesives incorporating magnetic nanoparticles was good, and they penetrated the dentin more effectively (53).

Nanoionomers

Nanoionomers, or glass ionomers (GI) incorporating nanoparticles, are used to make glass ionomer cement (GIC). A major reason why GIC is so popular is because of how it chemically adheres to the surface of the tooth. Fluoroaluminosilicate glass is enhanced with nanomers and nanoclusters (54). The fluoride-releasing and aesthetic features of the nanoionomer are achieved this way. In comparison to the traditional GIC, the nano-GI is more translucent and optically superior (55). By filling the crevices amongst the glass particles in GIC, the nanoparticles are manually combined along with the cement to minimize porosity (56). Pre-reacted GI technology was developed utilizing GIC and composite material to create "Giomer," and hydroxyapatite and glass powder to create "Mainomer." Bioactive glass, CPP-ACP, Reinforced GIC, Zirconomer, Chlorhexidine GIC, Nano Bioceramic reinforced GIC, and Ceramir and Giomer are new developments in GIC (57). On the surface of the enamel, bioactive glass displays remineralizing potential (58). By including bioactive glass nanoparticles, the resin-modified GI can be further altered (59). Nanoionomeric substances are advantageous due to their stronger bond formation, chemical stability, and insoluble nature (60).

Endodontic sealer

Endodontic sealers help to secure the root canal in three dimensions by providing a solid core material. These sealants support the root canal by adapting to the imperfections and voids in the canal. The antimicrobial activity, periapical repair, and hard tissue development are just a few of the features of sealer (61). They are categorized as GIC, zinc oxide eugenol, salicylate, epoxy resin, methacrylate resin, and tricalcium sealers based on their characteristics, content, and kind of setting reaction. Comparing the tricalcium silicate to AH Plus (62), it exhibits minimal microleakage. Recently, a bioceramic-based nanoparticle (Endosequence BC sealer) (63) was created. Delivery of the substance from 0.012 capillary needles in nanomaterials including nanoparticles aids in adjusting to the uneven dentin surface (64). Nano endodontic sealers have the advantage of sealing better than conventional sealers (65) and employing nanoparticles effectively acts as an antimicrobial agent (66). A new nano-based endodontic sealer called Nanoseal Plus, aids in filling the voids in the root canal. It consists of rod-shaped calcium phosphate hydroxyapatite nanoparticles with an average diameter of 40–60 nm which easily enter empty spaces (67). Recent research has used nanoparticles to improve the properties of primer adhesive, which will be used in future trials on amalgam.

Advantages of nanoparticles

While metals like iron do not have bactericidal qualities at the macroscopic level unlike the nanoscopic silver, copper, and zinc, they do have antimicrobial effect at the nanoscopic level. Antibacterial nanoparticles have numerous mechanisms through which they release metal ions, that penetrate into cell walls, and cause membrane damage (68). These particles have an effective encapsulation, protection, and delivering mechanism for releasing. micronutrients. The nanoparticles' reduced size demonstrates benefits such enhanced bioavailability, excellent optical clarity, gravitational segregation, and stability to agglomerate (69). The blood brain barrier can be crossed by the nanoparticles. Therefore, by adding on with properties, the use of nanoparticles results in the improvement of the property of traditional material.

Conclusion

Dental science is heavily reliant on nanotechnology. The nanoparticles have anti-inflammatory, anti-bacterial, and anti-cancer properties. The uses of the nanoparticles in implants, adhesives, nanocomposites, and primer-adhesives are numerous. Nanocomposites have several uses in restorative dentistry and have excellent strength and characteristics. When used with nanocomposites, GIC facilitates the combat of slow setting reactions, poor bond strengths, and diminished or weakened mechanical characteristics. Due to its potential uses and advantages, there is a growing demand for and interest in nano-based dental materials. Nanorobot use is a recent advancement that aids in the battle against microorganisms. Nanotechnology in dentistry has helped in overcoming many shortcomings part of restorative procedures and improved the oral health related quality of life.

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Conflict of interest

There is no conflict of interest

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Ethical consideration

Non applicable

Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

References

1. Uysal T, Yagci A, Uysal B, Akdogan G. Are nano-composites and nano-ionomers suitable for orthodontic bracket bonding? The European Journal of Orthodontics. 2010;32(1):78-82.

2. Rybachuk AV, Chekman IS, Nebesna TY. Nanotechnology and nanoparticles in dentistry. Pharmacol Pharm. 2009;1:18-21.

3. Kumar SR, Vijayalakshmi R. Nanotechnology in dentistry. Indian J Dent Res. 2006;17(2):62-5.

4. Sasalawad SS, Sathyajith NN, Shashibhushan K, Poornima P, Hugar SM, Roshan N. "Nanodentistry"-The Next Big Thing Is Small. International Journal of Contemporary Dental & Medical Reviews. 2014;2014.

5. Perdigao J. New developments in dental adhesion. Dental Clinics of North America. 2007;51(2):333-57.

6. Malathi Suresh DVS, Mahalaxmi S. Nanotechnology–an asset to dentistry!!! Int J Comm Dent. 2014;5(1):27-31.

7. Terry DA. Direct applications of a nanocomposite resin system: Part 1--The evolution of contemporary composite materials. Practical procedures & aesthetic dentistry: PPAD. 2004;16(6):417-22.

8. Wong DT. Salivary diagnostics powered by nanotechnologies, proteomics and genomics. The Journal of the American Dental Association. 2006;137(3):313-21.

9. Fayaz AM, Balaji K, Girilal M, Yadav R, Kalaichelvan PT, Venketesan R. Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria. Nanomedicine: Nanotechnology, Biology and Medicine. 2010;6(1):103-9.

10. Bruins MR, Kapil S, Oehme FW. Microbial resistance to metals in the environment. Ecotoxicology and environmental safety. 2000;45(3):198-207.

11. Beveridge T, Hughes M, Lee H, Leung K, Poole R, Savvaidis I, et al. Metal-microbe interactions: contemporary approaches. Advances in microbial physiology. 1996;38:177-243.

12. Kim JS, Kuk E, Yu KN, Kim J-H, Park SJ, Lee HJ, et al. Antimicrobial effects of silver nanoparticles. Nanomedicine: Nanotechnology, biology and medicine. 2007;3(1):95-101.

13. Dastjerdi R, Montazer M. A review on the application of inorganic nano-structured materials in the modification of textiles: focus on anti-microbial properties. Colloids and surfaces B: Biointerfaces. 2010;79(1):5-18.

14. Khodashenas B, Ghorbani HR. Synthesis of silver nanoparticles with different shapes. Arabian Journal of Chemistry. 2019;12(8):1823-38.

15. Khan I, Saeed K, Khan I. Nanoparticles: Properties, applications and toxicities. Arabian journal of chemistry. 2019;12(7):908-31.

16. Chahal S, Kumar A, Hussian FSJ. Development of biomimetic electrospun polymeric biomaterials for bone tissue engineering. A review. Journal of biomaterials science, polymer edition. 2019;30(14):1308-55.

17. Adams LK, Lyon DY, Alvarez PJ. Comparative eco-toxicity of nanoscale TiO2, SiO2, and ZnO water suspensions. Water research. 2006;40(19):3527-32.

18. Juan L, Zhimin Z, Anchun M, Lei L, Jingchao Z. Deposition of silver nanoparticles on titanium surface for antibacterial effect. International journal of nanomedicine. 2010;5:261.

19. Tjong SC. Novel nanoparticle-reinforced metal matrix composites with enhanced mechanical properties. Advanced engineering materials. 2007;9(8):639-52.

20. Schabes-Retchkiman P, Canizal G, Herrera-Becerra R, Zorrilla C, Liu H, Ascencio J. Biosynthesis and characterization of Ti/Ni bimetallic nanoparticles. Optical materials. 2006;29(1):95-9.

21. Gong P, Li H, He X, Wang K, Hu J, Tan W, et al. Preparation and antibacterial activity of Fe3O4@ Ag nanoparticles. Nanotechnology. 2007;18(28):285604.

http://dx.doi.org/10.52533/JOHS.2022.21209

22. Ahmad Z, Pandey R, Sharma S, Khuller G. Alginate nanoparticles as antituberculosis drug carriers: formulation development, pharmacokinetics and therapeutic potential. Indian journal of chest diseases and allied sciences. 2006;48(3):171.

23. Ju-Nam Y, Lead JR. Manufactured nanoparticles: an overview of their chemistry, interactions and potential environmental implications. Science of the total environment. 2008;400(1-3):396-414.

24. Barot T, Rawtani D, Kulkarni P, Hussain CM, Akkireddy S. Physicochemical and biological assessment of flowable resin composites incorporated with farnesol loaded halloysite nanotubes for dental applications. Journal of the mechanical behavior of biomedical materials. 2020;104:103675.

25. Khan AS, Aamer S, Chaudhry AA, Wong FS, Rehman IU. Synthesis and characterizations of a fluoride-releasing dental restorative material. Materials Science and Engineering: C. 2013;33(6):3458-64.

26. Jandt KD, Sigusch BW. Future perspectives of resin-based dental materials. Dental materials. 2009;25(8):1001-6.

27. Dresch W, Volpato S, Gomes JC, Ribeiro NR, Reis A, Loguercio AD. Clinical evaluation of a nanofilled composite in posterior teeth: 12-month results. Operative Dentistry. 2006;31(4):409-17.

28. Mikkilineni M, Rao AS, Tummala M, Elkanti S. Nanodentistry: New buzz in dentistry. European Journal of General Dentistry. 2013;2(02):109-13.

29. Gaiser S, Deyhle H, Bunk O, White SN, Müller B. Understanding nano-anatomy of healthy and carious human teeth: a prerequisite for nanodentistry. Biointerphases. 2012;7(1):4.

30. Chandki R, Kala M, Kumar KN, Brigit B, Banthia P, Banthia R. 'Nanodentistry': exploring the beauty of miniature. Journal of Clinical and Experimental Dentistry. 2012;4(2):e119.

31. Kanaparthy R, Kanaparthy A. The changing face of dentistry: nanotechnology. International journal of nanomedicine. 2011;6:2799.

32. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. The Journal of the American Dental Association. 2003;134(10):1382-90.

33. Mount GJ. Minimal intervention dentistry: rationale of cavity design. Operative Dentistry. 2003;28(1):92-9.

34. Hojati ST, Alaghemand H, Hamze F, Babaki FA, Rajab-Nia R, Rezvani MB, et al. Antibacterial, physical and mechanical properties of flowable resin composites containing zinc oxide nanoparticles. Dental Materials. 2013;29(5):495-505.

35. Turssi CP, Ferracane JL, Ferracane LL. Wear and fatigue behavior of nano-structured dental resin composites. Journal of Biomedical Materials Research Part B: Applied Biomaterials: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials. 2006;78(1):196-203.

36. Silva GA. Introduction to nanotechnology and its applications to medicine. Surgical neurology. 2004;61(3):216-20.

37. Ozak ST, Ozkan P. Nanotechnology and dentistry. European journal of dentistry. 2013;7(01):145-51.

38. Ben-Nissan B, Choi AH. Sol-gel production of bioactive nanocoatings for medical applications. Part 1: an introduction. 2006.

39. Choi A, Ben-Nissan B, Matinlinna J, Conway R. Current perspectives: calcium phosphate nanocoatings and nanocomposite coatings in dentistry. Journal of Dental Research. 2013;92(10):853-9.

40. Cramer N, Stansbury J, Bowman C. Recent advances and developments in composite dental restorative materials. Journal of dental research. 2011;90(4):402-16.

41. Kasraei S, Sami L, Hendi S, AliKhani M-Y, Rezaei-Soufi L, Khamverdi Z. Antibacterial properties of composite resins incorporating silver and zinc oxide nanoparticles on Streptococcus mutans and Lactobacillus. Restorative dentistry & endodontics. 2014;39(2):109-14.

42. de Oliveira AD, Beatrice CAG. Polymer nanocomposites with different types of nanofiller. Nanocomposites-Recent Evolutions. 2018:103-4.

43. Tanimoto Y, Kitagawa T, Aida M, Nishiyama N. Experimental and computational approach for evaluating the mechanical characteristics of dental composite resins with various filler sizes. Acta Biomaterialia. 2006;2(6):633-9.

 http://dx.doi.org/10.52533/JOHS.2022.21209

44. Khurshid Z, Zafar M, Qasim S, Shahab S, Naseem M, AbuReqaiba A. Advances in nanotechnology for restorative dentistry. Materials. 2015;8(2):717-31.

45. Ravinthar K. Recent advancements in laminates and veneers in dentistry. Research Journal of Pharmacy and Technology. 2018;11(2):785-7.

46. Re D, Augusti G, Amato M, Riva G, Augusti D. Esthetic rehabilitation of anterior teeth with laminates composite veneers. Case reports in dentistry. 2014;2014.

47. Campbell TA, Ivanova OS. 3D printing of multifunctional nanocomposites. Nano Today. 2013;8(2):119-20.

48. Angel Villegas N, Silvero Compagnucci MJ, Sainz Ajá M, Rocca DM, Becerra MC, Fabián Molina G, et al. Novel antibacterial resin-based filling material containing nanoparticles for the potential one-step treatment of caries. Journal of healthcare Engineering. 2019;2019.

49. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: from the IV generation to the universal type. Annali di stomatologia. 2017;8(1):1.

50. Melo MAS, Cheng L, Zhang K, Weir MD, Rodrigues LK, Xu HH. Novel dental adhesives containing nanoparticles of silver and amorphous calcium phosphate. Dental Materials. 2013;29(2):199-210.

51. Zhang M, Liu M, Bewick S, Suo Z. Nanoparticles to increase adhesive properties of biologically secreted materials for surface affixing. Journal of biomedical nanotechnology. 2009;5(3):294-9.

52. Althomali YM, Ebrahim MI. Microshear bond strength of Nano-Bond adhesive containing nanosized aluminum trioxide particles. journal of orthodontic science. 2017;6(2):71.

53. Li Y, Hu X, Xia Y, Ji Y, Ruan J, Weir MD, et al. Novel magnetic nanoparticle-containing adhesive with greater dentin bond strength and antibacterial and remineralizing capabilities. Dental Materials. 2018;34(9):1310-22.

54. Khan AS, Khan M, Rehman IU. Nanoparticles, properties, and applications in glass ionomer cements. 2012.

55. Basso M. Teeth restoration using a high-viscosity glass ionomer cement: The Equia® system. Journal of Minimum Intervention in Dentistry. 2011;4(3):74-6.

56. Gjorgievska E, Van Tendeloo G, Nicholson JW, Coleman NJ, Slipper IJ, Booth S. The incorporation of nanoparticles into conventional glass-ionomer dental restorative cements. Microscopy and microanalysis. 2015;21(2):392-406.

57. GPV S, Elsa N, Agrawal A. Newer Advances In Glass Ionomer Cement: A Review. 2016.

58. Rajendran R, Kunjusankaran RN, Sandhya R, Anilkumar A, Santhosh R, Patil SR. Comparative evaluation of remineralizing potential of a paste containing bioactive glass and a topical cream containing casein phosphopeptide-amorphous calcium phosphate: An in vitro study. Pesquisa brasileira em odontopediatria e clinica integrada. 2019;19.

59. Hussainy SN, Nasim I, Thomas T, Ranjan M. Clinical performance of resin-modified glass ionomer cement, flowable composite, and polyacid-modified resin composite in noncarious cervical lesions: One-year follow-up. Journal of conservative dentistry: JCD. 2018;21(5):510.

60. Najeeb S, Khurshid Z, Zafar MS, Khan AS, Zohaib S, Martí JMN, et al. Modifications in glass ionomer cements: nano-sized fillers and bioactive nanoceramics. International journal of molecular sciences. 2016;17(7):1134.

61. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E. Endodontic sealers based on calcium silicates: a systematic review. Odontology. 2019;107(4):421-36.

62. Komabayashi T, Colmenar D, Cvach N, Bhat A, Primus C, Imai Y. Comprehensive review of current endodontic sealers. Dental materials journal. 2020;39(5):703-20.

63. Topçuoğlu HS, Tuncay Ö, Karataş E, Arslan H, Yeter K. In vitro fracture resistance of roots obturated with epoxy resin–based, mineral trioxide aggregate–based, and bioceramic root canal sealers. Journal of endodontics. 2013;39(12):1630-3.

64. Koch K, Brave D. The increased use of bioceramics in endodontics. Dentaltown. 2009;10:39-43.

65. Desouky AA, Negm MM, Ali MM. Sealability of Different Root Canal Nanosealers: Nano Calcium Hydroxide and Nano Bioactive Glass. The Open Dentistry Journal. 2019;13(1).

66. Barros J, Silva MG, Rôças IN, Gonçalves LS, Alves FF, Lopes MA, et al. Antibiofilm effects of endodontic sealers containing quaternary ammonium

polyethylenimine nanoparticles. Journal of endodontics. 2014;40(8):1167-71.

67. Singh H, Markan S, Kaur M, Gupta G, Singh H, Kaur M. Endodontic sealers: Current concepts and comparative analysis. Dent Open J. 2015;2(1):32-7.

68. Seil JT, Webster TJ. Antimicrobial applications of nanotechnology: methods and literature. International journal of nanomedicine. 2012;7:2767.

69. Joye IJ, Davidov-Pardo G, McClements DJ. Nanotechnology for increased micronutrient bioavailability. Trends in food science & technology. 2014;40(2):168-82.

http://dx.doi.org/10.52533/JOHS.2022.21209