Original Article

NANO PARTICLES USED IN DENTISTRY

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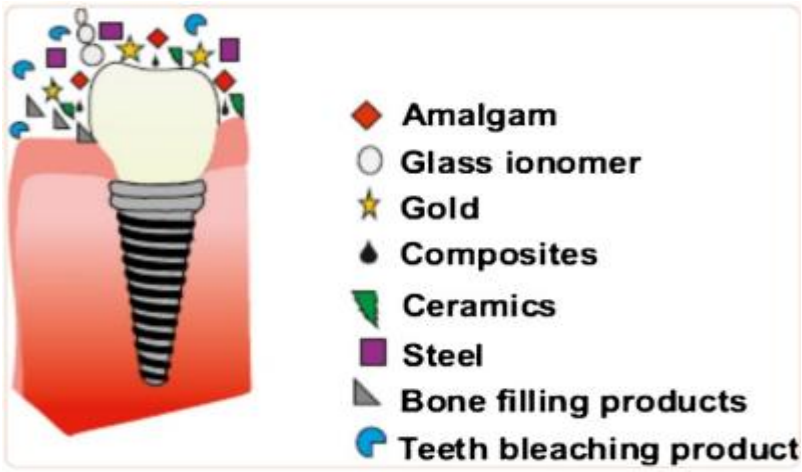
Abstract

Nanomaterials are highly advanced, essential for quick detection, and helpful in treating a variety of ailments in the health sector due to their distinctive and superior properties, such as high surface area and nanoscale size. The creation of sophisticated nanomaterials and the application of those materials in dentistry have been made possible through collaborative efforts from a variety of disciplines. When compared to their conventional equivalents, these advanced nanomaterials can provide diagnostic and therapeutic procedures with more promising results. In our daily lives, nanotechnology is used extensively, especially in medicine. The chemical, physical, as well as the biological aspects of nanostructures are taken into consideration while choosing nanoparticles for usage in the field of nano dentistry. Nanostructures are employed in dental innovations or dental diagnoses. Some nanoparticles are utilized in dental implants, prosthetics, and medications used to prevent oral diseases. Additionally, nanomaterials administer oral fluids or medications, preventing and treating various oral diseases (such as oral cancer), and upholding oral health care to a significant degree. The utilization of many commonly used nanoparticles in the field of dentistry is summarized in this paper. Nanotechnology makes it simple to examine and work with the atoms, chemical bonds, and molecules that make up different chemicals.

Keywords: Nanoparticles, Dental filling, Dental implant, Dental polishing, Nanomaterials; Nano-fillers; Dental Nanocomposite; Nano-biotechnology

INTRODUCTION

The oral cavity contains teeth, which are made up of several components including dentin, enamel, cementum, pulp, and periodontal ligament. The purpose of teeth is to cut and chew food so that it will be simpler to swallow and digest. To protect the teeth, a variety of substances are utilized in dentistry.[1] Amalgam with good mechanical qualities is used to fill teeth. To seal crowns and bridges, amalgam composite is employed. An oral polymerization light was inserted to permanently harden the sealant. Deciduous teeth can be temporarily filled with glass ionomers.[2] It has good tolerance capacity and protects crowns and bridges indefinitely. Gold is the perfect material for prosthetics since it is rigid, precise, and safe. Used in fixed prosthetics (crowns and bridges) is ceramic.



For instance, amalgam's primary drawback is that it contains mercury, which is harmful to human health.[3] Composite fillings are extremely susceptible to cold. Ceramics are quite hard by nature yet occasionally crack. Nanoparticles have been introduced in dentistry while taking these drawbacks into consideration. This review focuses on the usage of nanoparticles in several dental specialties and provides a thorough detail of nanomaterials according to their use in dentistry.

1. Nano particles used in dentistry

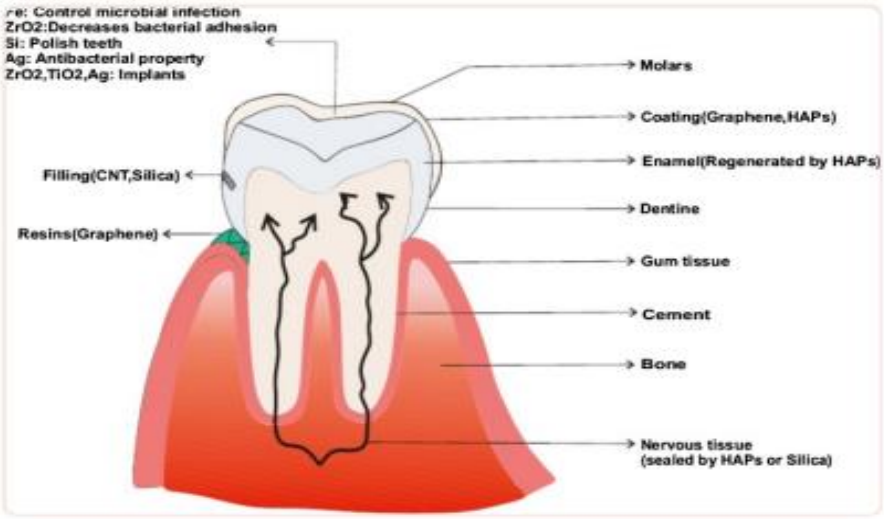
(1) Carbon Nanotubes

Carbon nanotubes (CNTs) have distinctive mechanical and electrical characteristics. The C22C covalent bond and hexagonal arrangement of CNTs are what give them their strength and flexibility. CNTs also exhibit electrical and thermal conductivity (semi conductivity). Carbon nanotubes are employed as a candidate for dental fillings and other applications due to its good mechanical and electrical qualities, including temperature resistance, thermal transfer efficiency, high strength, and decreased density.[4] In Kanzius RF Therapy, active medicines are delivered to living cells via CNTs needles.[5]

(2) Graphene

One atom thick densely packed planar sheet with a honeycomb crystal lattice make up the structure of graphene, an allotrope of carbon with sp2 hybridized carbon atoms. Because it forms a homogeneous crystalline structure without any voids or structural dislocations, graphene is the thinnest material known. This characteristic gave graphene additional physical characteristics. Graphene's conducting electrons mostly behave like neutrons or electrons that travel at the speed of light. Thus, graphene is employed in photovoltaics, biodevices, ultracapacitors for illness diagnosis and detection as well as the construction of surfaces that are resistant to bacteria.[6]

Dental caries development (Streptococcus mutants are one of the etiological agents in dental caries production) and other periodontal illnesses depend on oral biofilms. Implants can act as a tooth replacement. Due to the likelihood of implant failure, biofilms are crucial.[7] A graphene/zinc oxide nanocomposite (GZNC) may be able to dissolve a streptococcus mutans biofilm.[8]



(3) Hydroxy apatite (HAp)

The usage of hydroxyl apatite nanoparticles in healthcare and dentistry is widespread. Because of its similar chemical structure to teeth and bone, it is a biocompatible material for physiological processes. This is the primary make-up of the body's mineralized tissues (Ca (PO) 2(OH)). 97% of enamel is made of this natural calcium phosphate ceramic.[9] The building blocks of tooth enamel, which is the body's toughest tissue, are HAp nano crystals. Since teeth are acellular in nature, it makes no sense that they could be rebuilt like bones.[10]

Recent advances in nanotechnology are revealing fresh perspectives on the use of nano-hydroxyapatite in dentistry. The dental tubules can quickly and easily assimilate the nanosized HAp particles.[11] The tubule's job is to close the gap, keeping the nerves from being exposed to outside stimuli. Thus, reducing dental hypersensitivity. Because HAp NPs have a larger surface area, they can attach to proteins as well as bacterial and plaque fragments very strongly.[12][31] They can attach to tooth enamel and dentin apatite due to their strong biological activity and reactivity. The tiny cavities in the enamel caused by acidic erosion can fit nicely with hydroxyl apatite nanoparticles.

Iron oxide

In the fields of biology and medicine, iron compounds (FeOx) nanoparticles play a significant role.[13]

Due to their biocompatibility and lack of toxicity for humans, magnetite and maghemite, two typical types of iron oxide nanoparticles, are the most popular in the field of biomedical science.[14]

Iron oxide is also easily broken down, which is advantageous for in vivo applications.

Due to their protective coating of exopolymers that embed the microorganisms in a matrix that is impermeable to immune cells and many antibiotics, bacterial biofilms on dental implants are challenging for antibiotics to eradicate.[15]

(4) Zirconia

The usage In dental science, zirconia (Zirconium dioxide, ZrO) is very important. It resembles teeth in color and has comparable metallic characteristics. Zirconia is an insoluble chemical oxide in water. Thus, it has low cytotoxicity and lessens bacterial adherence. ZrO is now a widely used biomaterial for dental implants as a result.[16] Zirconia implants feature excellent corrosion and wear resistance as well as sensible biocompatibility.[17]

Additionally, ZrO has a high fracture resistance because of its ability to retain energy when converting polygonal molecules into monoclinic ones.

Zirconia nanoparticles are a bio-inert substance; mammalian flesh cannot effectively encapsulate them, and they leave almost no trace behind.[18]

(5) Silica

Because of their size, surface area, biocompatibility, low toxicity, low density, and adsorption capability, silica-based NPs play a vital role in nanotechnology.[19] SiNPs are employed in many areas of medical science to treat genetic abnormalities to diagnose and control disease.[20] Consequently, Silica NPs are employed in biomedical research for purposes like medication delivery, enzyme support, and biosensors. Silica particles are utilized in polishing due to their affordability and biocompatibility. Dental hypersensitivity is treated using modified silica nanoparticles.[21] The risk of dental hypersensitivity increases as a result of enamel erosion, which exposes dentinal tubules. Over time, a variety of desensitizing medications have been commercially available with the goal of occluding dental tubules. But none of them are dependable or consistent.[22] To safeguard the enamel surfaces, teeth are frequently polished.

(6) Titania

TiO nanoparticles are mostly utilized in the medical and dental industries. By triggering type 1 antigen/antibody and type IV complex reactions, the insertion of implants causes an allergic reaction.[23] Microbe adhesion to Titania implants, however, has a significant impact on the recovery of teeth and demonstrates the long-term impact on implants.[24] Plaque can develop on implants as a result of roughness or chemical breakdown inside the oral cavity. The creation of inorganic nano porous materials, which are extensively exploited to create drug-releasing implants, occurs in bone in response to physically changed titanium implants.[25] Dental RBCs' hardness and strength are increased through surface modification, and TiO linked to and dispersed within a resin matrix are also impacted.

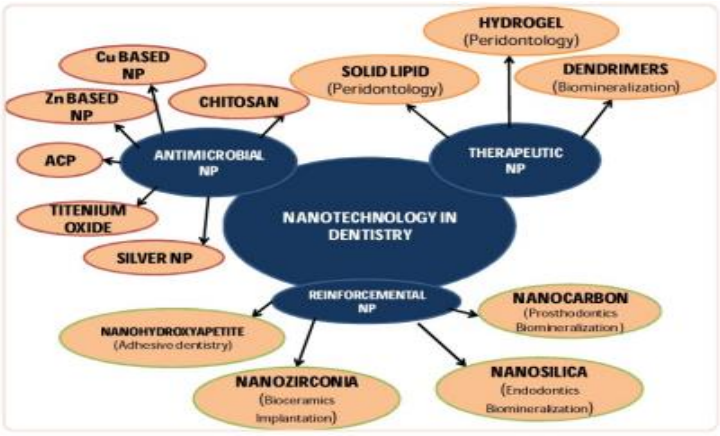
(7) Silica

It is well known that silver compounds have antibacterial properties. As nanotechnology develops, more silver nanoparticles are produced (AgNPs). AgNPs are commonly utilized in humidifiers, washing machines, toothpaste, shampoo, kitchen appliances, textiles, and nursing bottles.[26] Additionally, AgNPs have been investigated for use in endodontics, dental restoratives, dental prostheses, and dental implants, among other dental applications. AgNP incorporation improves oral health by reducing microbial colonization over dental components.[27] The nanoparticles have an extremely low level of antibacterial activity because of their small size and huge surface area.

In addition to altering base pairing, DNA unwinding, cell wall formation, and respiratory activities, silver can interfere with DNA and proteins by interacting with —SH groups.[28] This causes bacterial mortality.

2. APPLICATION OF NANOPARTICLES IN DENTISTRY

Due to their improved absorption, effectiveness, and decreased dosage requirements, nanomaterials have the potential to offer better control over managing a variety of deadly oral disorders.[29] The use of nanoparticles in dentistry has had a significant influence and created new opportunities for a variety of applications with the development of new procedures.



2.1 Nanoparticles used in Periodontics

The field of dentistry known as periodontics focuses solely on illnesses that affect the tissues that support teeth, including the gingiva, periodontal ligament, cementum, alveolar bone, and mucosa.[30] For the therapy of periodontal disorders, a variety of therapies are available; some of them combine medical and surgical approaches. Pharmaceutical treatments use naturally occurring medication compounds.

Macroparticles have a hard time entering the periodontal pockets. On the other hand, nanoparticles can more easily penetrate subgingival regions due to their small diameters.[31][12] As an illustration, the use of nanoparticles in medication delivery for the treatment of periodontal disease with triclosan (TCS) has been successful.[32] Tetracycline nanoparticles (Tet NPs) have also been researched as a possible periodontal therapy. Tetracycline-loaded microspheres patches were marketed as Arestin® and Nanogen® by Valeant in Bridgewater, Massachusetts, the United States (Orthogen, Springfield, IL, USA).[33] It is applied by placing a patch inside the periodontal pocket, which causes a prolonged medication release into the afflicted area.

2.2 Nanoparticles used in Prosthodontics

With the use of biocompatible substitutes, prosthodontics deals with the diagnosis, treatment planning, total oral rehabilitation, and preservation of the normal oral function of patients with clinical disorders linked to missing teeth or oral and maxillofacial tissues.[34] Dental implants and acrylic resins are examples of next generation materials with improved qualities that can be used for a variety of prosthodontic treatment procedures. Using nanoceramic material to make dentures shows exceptional strength, color stability, and low electrical and thermal conductivity.[35]

A prosthodontic denture has been made with titanium, cobalt chromium, and molybdenum alloys using a variety of various metal combinations. Compared to stainless steel or gold alloy, their combinations exhibit higher mechanical qualities and corrosion resistance.[36]

In the creation of prosthodontic dentures, metal nanoparticles like those made of hydroxyapatite and titanium oxide have better biological acceptance than conventional metals.

A considerable increase in transverse strength, improved biological compatibility, increased surface hardness, and decreased water sorption and solubility are all demonstrated in prosthodontics when nanofillers are added to polymethylmethacrylate (PMMA).[37]

2.3 Nanoparticles used in Oral and Maxillofacial Surgery

The area of dentistry known as oral and maxillofacial surgery focuses on treating disorders of the mouth and face that affect the hard and soft tissues in the oral (mouth) and maxillofacial (jaws and face) regions. Surgery is necessary to repair bone deformities brought on by various dental diseases or trauma that result in abnormal face characteristics.[38] Advanced nanomaterials outperform conventional treatment solutions in terms of effectiveness and biocompatibility. Due to their capacity to encourage osteogenesis and biomineralization of cells, they can also be utilized as scaffolds to produce new bone.[39]

While targeting cancerous tissue, localized nanodrug delivery can also aid in protecting neighboring healthy tissues. Magnetic nanoparticles have the potential to be employed for tumor-targeted drug delivery therapy, according to several studies.[40] They can be administered intravenously straight to the tumor site tissue, and because of their nano size, only little doses of medication are needed to achieve the desired effect of tumor regression by careful drug delivery targeting.

2.4 Nanoparticles used in Conservative Dentistry and Endodontics

The dental specialization known as endodontics focuses on the biology of healthy tooth pulp as well as the causes of and remedies for pulp disorders and injuries related with periradicular diseases. One of the primary causes of the deep dental caries is oral microorganisms, which can result in dental caries and a variety of endodontic operations, including root canal therapy.[41] The following are some of the ways in which nanoparticles are used in dentistry –

- It is used in the treatment of dental hypersensitivity because hydroxyapatite nanocrystals in toothpaste are used for blocking of dentinal tubules.[42]
- Nano filled glass ionomer cement has better mechanical and optical properties.[43]
- Nanoparticles are filled with restorative composite resins because they have higher filler loading, better mechanical properties and a glossy surface.[44]
- Nano filled bonding agents are more resistant to degradation and have better bonding properties.[45]
- They are also used as endodontic sealers. QPEI NP's nanoparticles are used as fillers in commercially available endodontic sealers, for instance Guttaflow, Epiphany and AH plus for its antibacterial action.{46}
- They also help in remineralization of the tooth structure: combination of PVP and ACP nano fibers are used for remineralization of demineralized dentine in vitro.[47]

Nanotechnology can significantly contribute to the creation of cutting-edge endodontic materials for use in endodontic procedures.[48][49] Endodontic procedures need the use of a variety of materials, including gutta-percha canal disinfectant, dental amalgam, glass ionomer cements (GIC), dental composite, and sealants. Antibacterial nanoparticles added to endodontic materials can improve their qualities using nanotechnology, helping to avoid repeated infections and the failure of root canal procedures.[49][48] According to a newly published study, adding biopolymeric nanoparticles to root canal cleaners significantly increased their antibacterial efficacy. In a different investigation, the addition of QPEI (quaternary ammonium polyethyleneimine) NPs enhanced the root canal sealer's antibacterial activity against biofilms of (Enterococcus faecalis) strains of E. faecalis.[50]

2.5 Nanomaterials in Orthodontics and Dentofacial Orthopaedics

The area of dentistry known as orthodontics and dentofacial orthopedic surgery focuses primarily on the diagnosis, prevention, and treatment of incorrectly positioned teeth. The teeth should be in their optimal positions for the oral cavity to function normally, however due to poor dental health, malocclusion, tooth crowding, or spaces between teeth, orthodontic treatment is necessary.[51]

The use of nanotechnology in orthodontic applications is still in its adolescence. Manufacturers are continuously researching and commercially marketing advanced nanomaterials. Nanoparticle coating can be used to reduce mechanical resistance and friction among orthodontic wires and brackets.[52] Orthodontic materials with antibacterial nanoparticle coatings can stop dental plaque from forming around the appliances and stop dental caries that is related to orthodontic therapy.[53]

2.6 Nanomaterials in Oral Medicine and Radiology

The branch of dentistry known as oral medicine is focused on the non-surgical treatment of diseases other than dental ones that impact the oral and face areas.

Numerous oral disorders can be caused by poor oral health. Early and correct detection of oral disorders is essential for maintaining good oral health. Better oral disease treatment and superior imaging are now possible because of nanotechnology.

Oral pharmaceutical approaches based on nanotechnology have several advantages over the traditional method.[54]

Nanoparticles prefer to develop stronger chemical or physical bonds because they have unpaired atoms and a vast surface area, which gives them enhanced mechanical and physical capabilities.[55] Oral medicine has employed organic and inorganic nanoparticles like Silica, Zirconia, HA, and Titanium dioxide for therapeutic purposes.

When exposed to even very low doses of ionizing radiation, Nano phosphor scintillators, which rapidly generate visible light, are used to test digital imaging.[56] Compared to conventional approaches, this nano imaging technique produces high-quality images with a very low radiation requirement, which can be particularly advantageous for dental applications.

2.7 Nanomaterials in Preventive Dentistry

Nanotechnology can be used in preventative dentistry to shield against lesion-causing agents and assist avoid carious lesions. Early bacterial biofilms that grow on the tooth's surface and cause tooth decay are what cause dental caries.[57] Dental restorative materials containing nano apatite particles can help damaged tooth structures remineralize.

2.8 Nanomaterials in Restorative Dentistry

The diagnosis and treatment of problems affecting the teeth and their supporting structures are the focus of restorative dentistry. The repair of damaged tooth structures, restoration of tooth function, and improvement of aesthetics all require advanced methods.[58]

Manufacturing of biocompatible and non-toxic dental restorative materials, including GIC, dental composite, dental implants, and endodontic materials, has benefited considerably from nanotechnology.[59] In the past few years, resin-based dental restorative materials have made significant progress. The dental composite resin matrix's mechanical characteristics, minimal polymerization shrinkage, strong abrasion resistance, and surface hardness can all be considerably improved using nanoparticles.

3. CONCLUSION

The use of nanotechnology in clinical dental practices will be significant. To improve oral healthcare and make it less stressful for dental surgeons, nanomaterials are incorporated in toothpaste and other washing solutions. The

dental issues can be addressed using new nano strategies. Nanomaterials are more efficient than traditional materials and are utilized in dental fillings, polishing the surface of the enamel to prevent cavities, and implant materials. Some nanoparticles have antibacterial properties and stop the growth of bacteria.

s. The treatments in dentistry may be improved by further investigation into nanotechnology and antibacterial materials. The success of these extremely sophisticated restorative nanomaterials in dentistry depends on substantial research in this area.

Before using new material in clinical settings, it is critical that sufficient clinical data be made available. The capabilities and potential applications of nanotechnology in the dentistry industry are discussed in this review article. Patients are drawn to dentistry because of nano dentistry's cost- and time-saving benefits as well as its ability to shield patients from psychological harm. The creation of modified nanoparticles will undoubtedly aid in the treatment of dental issues. Although the impact of nanotechnology on the treatment of oral diseases is still limited, the rapid advancement of research ensures new developments are likely soon. The accuracy of the processes in this technique can result in better social, economic, and oral health results for people soon, when this technology could become the foundation of dental and medical science.

Conflict of interests:-

The authors declare that there are no conflicts of interest regarding the publication of this paper.

REFERENCES -

1. Zimmerman B, Shumway KR, Jenzer AC. Physiology, Tooth. InStatPearls [Internet] 2022 Apr 14. StatPearls Publishing.

2. Lohbauer U. Dental glass ionomer cements as permanent filling materials?—Properties, limitations future trends. Materials. 2009 Dec 28;3(1):76-96.

3. Rathore M, Singh A, Pant VA. The dental amalgam toxicity fear: a myth or actuality. Toxicology international. 2012 May;19(2):81.

4. Castro-Rojas MA, Vega-Cantu YI, Cordell GA, Rodriguez-Garcia A. Dental applications of carbon nanotubes. Molecules. 2021 Jul 22;26(15):4423.

5. Sanginario A, Miccoli B, Demarchi D. Carbon nanotubes as an effective opportunity for cancer diagnosis and treatment. Biosensors. 2017 Feb 15;7(1):9.

6. Singh A, Ahmed A, Sharma A, Arya S. Graphene and its derivatives: Synthesis and application in the electrochemical detection of analytes in sweat. Biosensors. 2022 Oct 21;12(10):910.

7. Dhir S. Biofilm and dental implant: The microbial link. Journal of Indian Society of Periodontology. 2013 Jan;17(1):5.

8. Kulshrestha S, Khan S, Meena R, Singh BR, Khan AU. A graphene/zinc oxide nanocomposite film protects dental implant surfaces against cariogenic Streptococcus mutans. Biofouling. 2014 Nov 26;30(10):1281-94.

9. Meyer F, Amaechi BT, Fabritius HO, Enax J. Overview of calcium phosphates used in biomimetic oral care. The open dentistry journal. 2018;12:406.

10. Li J, Parada C, Chai Y. Cellular and molecular mechanisms of tooth root development. Development. 2017 Feb 1;144(3):374-84.

11. Raura N, Garg A, Arora A, Roma M. Nanoparticle technology and its implications in endodontics: A review. Biomaterials Research. 2020 Dec;24(1):1-8.

12. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry: A review. Journal of oral biology and craniofacial research. 2018 Jan 1;8(1):58-67.

13. Arias LS, Pessan JP, Vieira AP, Lima TM, Delbem AC, Monteiro DR. Iron oxide nanoparticles for biomedical applications: A perspective on synthesis, drugs, antimicrobial activity, and toxicity. Antibiotics. 2018 Jun 9;7(2):46.

14. Montiel Schneider MG, Martín MJ, Otarola J, Vakarelska E, Simeonov V, Lassalle V, Nedyalkova M. Biomedical Applications of Iron Oxide Nanoparticles: Current Insights Progress and Perspectives. Pharmaceutics. 2022 Jan 16;14(1):204.

15. Esteves GM, Esteves J, Resende M, Mendes L, Azevedo AS. Antimicrobial and antibiofilm coating of dental implants—past and new perspectives. Antibiotics. 2022 Feb 11;11(2):235.

16. Chopra D, Jayasree A, Guo T, Gulati K, Ivanovski S. Advancing dental implants: Bioactive and therapeutic modifications of zirconia. Bioactive Materials. 2021 Nov 5.

17. Apratim A, Eachempati P, Salian KK, Singh V, Chhabra S, Shah S. Zirconia in dental implantology: A review. Journal of International Society of Preventive & Community Dentistry. 2015 May;5(3):147.

18. Kumari N, Sareen S, Verma M, Sharma S, Sharma A, Sohal HS, Mehta SK, Park J, Mutreja V. Zirconia-based nanomaterials: recent developments in synthesis and applications. Nanoscale Advances. 2022.

19. Khan I, Saeed K, Khan I. Nanoparticles: Properties, applications and toxicities. Arabian journal of chemistry. 2019 Nov 1;12(7):908-31.

20. Alliance G. Understanding genetics: a district of Columbia guide for patients and health professionals.

21. Tang L, Cheng J. Nonporous silica nanoparticles for nanomedicine application. Nano today. 2013 Jun 1;8(3):290-312.

22. Miglani S, Aggarwal V, Ahuja B. Dentin hypersensitivity: Recent trends in management. Journal of conservative dentistry: JCD. 2010 Oct;13(4):218.

23. Chaturvedi TP. Allergy related to dental implant and its clinical significance. Clinical, Cosmetic and Investigational Dentistry. 2013;5:57.

24. Kligman S, Ren Z, Chung CH, Perillo MA, Chang YC, Koo H, Zheng Z, Li C. The impact of dental implant surface modifications on osseointegration and biofilm formation. Journal of clinical medicine. 2021 Jan;10(8):1641.

25. Ma X, Gao Y, Zhao D, Zhang W, Zhao W, Wu M, Cui Y, Li Q, Zhang Z, Ma C. Titanium implants and local drug delivery systems become mutual promoters in orthopedic clinics. Nanomaterials. 2021 Dec 24;12(1):47.

26. Elle RE, Gaillet S, Vidé J, Romain C, Lauret C, Rugani N, Cristol JP, Rouanet JM. Dietary exposure to silver nanoparticles in Sprague–Dawley rats: effects on oxidative stress and inflammation. Food and chemical toxicology. 2013 Oct 1;60:297-301.

27. Fernandez CC, Sokolonski AR, Fonseca MS, Stanisic D, Araújo DB, Azevedo V, Portela RD, Tasic L. Applications of silver nanoparticles in dentistry: advances and technological innovation. International journal of molecular sciences. 2021 Mar 2;22(5):2485.

28. Sun Q, Xie X, Song Y, Sun L. A review on silver-mediated DNA base pairs: methodology and application. Biomaterials Research. 2022 Dec;26(1):1-7.

29. Singh L, Kruger HG, Maguire GE, Govender T, Parboosing R. The role of nanotechnology in the treatment of viral infections. Therapeutic advances in infectious disease. 2017 Jul;4(4):105-31.

30. Könönen E, Gursoy M, Gursoy UK. Periodontitis: a multifaceted disease of tooth-supporting tissues. Journal of clinical medicine. 2019 Jul 31;8(8):1135.

31. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry: A review. Journal of oral biology and craniofacial research. 2018 Jan 1;8(1):58-67.

32. Pinon-Segundo E, Ganem-Quintanar A, Alonso-Pérez V, Quintanar-Guerrero D. Preparation and characterization of triclosan nanoparticles for periodontal treatment. International journal of pharmaceutics. 2005 Apr 27;294(1-2):217-32.

33. Barot T, Rawtani D, Kulkarni P. Nanotechnology-based materials as emerging trends for dental applications. Reviews on Advanced Materials Science. 2021 Jan 1;60(1):173-89.

34. Vosselman N, Alberga J, Witjes MH, Raghoebar GM, Reintsema H, Vissink A, Korfage A. Prosthodontic rehabilitation of head and neck cancer patients—Challenges and new developments. Oral diseases. 2021 Jan;27(1):64-72.

35. Pasha M, Muhammad N, Shahnawaz S, Najmi Y, Shahroz N, Liaqat S. Ceramic Nanomaterials in Dental Applications. Nanoengineering of Biomaterials. 2022 Feb 14:123-44.

36. Kong D, Dong C, Ni X, Li X. Corrosion of metallic materials fabricated by selective laser melting. npj Materials Degradation. 2019 Jun 11;3(1):1-4.

37. Zafar MS. Prosthodontic applications of polymethyl methacrylate (PMMA): An update. Polymers. 2020 Oct 8;12(10):2299.

38. Titsinides S, Agrogiannis G, Karatzas T. Bone grafting materials in dentoalveolar reconstruction: A comprehensive review. Japanese dental science review. 2019 Nov 1;55(1):26-32.

39. Jiang S, Wang M, He J. A review of biomimetic scaffolds for bone regeneration: Toward a cell-free strategy. Bioengineering & Translational Medicine. 2021 May;6(2):e10206.

40. Liu JF, Jang B, Issadore D, Tsourkas A. Use of magnetic fields and nanoparticles to trigger drug release and improve tumor targeting. Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology. 2019 Nov;11(6):e1571.

41. Rôças IN, Alves FR, Rachid CT, Lima KC, Assuncao IV, Gomes PN, Siqueira Jr JF. Microbiome of deep dentinal caries lesions in teeth with symptomatic irreversible pulpitis. PLoS One. 2016 May 2;11(5):e0154653.

42. Low SB, Allen EP, Kontogiorgos ED. Reduction in dental hypersensitivity with nano-hydroxyapatite, potassium nitrate, sodium monoflurophosphate and antioxidants. The Open Dentistry Journal. 2015(9):92.

43. Menezes-Silva R, Cabral RN, Pascotto RC, Borges AF, Martins CC, Navarro MF, Sidhu SK, Leal SC. Mechanical and optical properties of conventional restorative glass-ionomer cements-a systematic review. Journal of Applied Oral Science. 2019 Feb 21;27.

44. Azmy E, Al-Kholy MR, Fattouh M, Kenawi LM, Helal MA. Impact of nanoparticles additions on the strength of dental composite resin. International Journal of Biomaterials. 2022 Jul 5;2022.

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

46. Kesler Shvero D, Abramovitz I, Zaltsman N, Perez Davidi M, Weiss EI, Beyth N. Towards antibacterial endodontic sealers using quaternary ammonium nanoparticles. International endodontic journal. 2013 Aug;46(8):747-54.

47. Fletcher J, Walsh D, Fowler CE, Mann S. Electrospun mats of PVP/ACP nanofibres for remineralization of enamel tooth surfaces. CrystEngComm. 2011;13(11):3692-7.

48. Zakrzewski W, Dobrzyński M, Zawadzka-Knefel A, Lubojański A, Dobrzyński W, Janecki M, Kurek K, Szymonowicz M, Wiglusz RJ, Rybak Z. Nanomaterials application in endodontics. Materials. 2021 Sep 14;14(18):5296.

49. Zakrzewski W, Dobrzyński M, Zawadzka-Knefel A, Lubojański A, Dobrzyński W, Janecki M, Kurek K, Szymonowicz M, Wiglusz RJ, Rybak Z. Nanomaterials application in endodontics. Materials. 2021 Sep 14;14(18):5296.

50. Barros J, Silva MG, Rôças IN, Gonçalves LS, Alves FF, Lopes MA, Pina-Vaz I, Siqueira Jr JF. Antibiofilm effects of endodontic sealers containing quaternary ammonium polyethylenimine nanoparticles. Journal of endodontics. 2014 Aug 1;40(8):1167-71.

51. Pakdaman A, Meighani G. Diagnosis and management of supernumerary (mesiodens): a review of the literature. Frontiers in Dentistry. 2010:41-9.

52. Indumathi P, Singh D, Sharma VK, Shukla NK, Chaturvedi TP. The effect of various nanoparticle coating on the frictional resistance at orthodontic wire and bracket interface: A systematic review. journal of orthodontic science. 2022 Jan 1;11(1):7.

53. Zakrzewski W, Dobrzynski M, Dobrzynski W, Zawadzka-Knefel A, Janecki M, Kurek K, Lubojanski A, Szymonowicz M, Rybak Z, Wiglusz RJ. Nanomaterials application in orthodontics. Nanomaterials. 2021 Jan 28;11(2):337.

54. Gelperina S, Kisich K, Iseman MD, Heifets L. The potential advantages of nanoparticle drug delivery systems in chemotherapy of tuberculosis. American journal of respiratory and critical care medicine. 2005 Dec 15;172(12):1487-90.

55. Issa B, Obaidat IM, Albiss BA, Haik Y. Magnetic nanoparticles: surface effects and properties related to biomedicine applications. International journal of molecular sciences. 2013 Oct 25;14(11):21266-305.

56. Kamkaew A, Chen F, Zhan Y, Majewski RL, Cai W. Scintillating nanoparticles as energy mediators for enhanced photodynamic therapy. ACS nano. 2016 Apr 26;10(4):3918-35.

57. Cheng L, Zhang K, Weir MD, Melo MA, Zhou X, Xu HH. Nanotechnology strategies for antibacterial and remineralizing composites and adhesives to tackle dental caries. Nanomedicine. 2015 Mar;10(4):627-41.

58. Kelleher MG, Bomfim DI, Austin RS. Biologically based restorative management of tooth wear. International Journal of Dentistry. 2012 Jan 1;2012.

59. Melo MA, Guedes SF, Xu HH, Rodrigues LK. Nanotechnology-based restorative materials for dental caries management. Trends in biotechnology. 2013 Aug 1;31(8):459-67.