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Update in Endodontic Treatment by Application of Nanoparticles_ Review

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Abstract

Nanomaterials are defined as materials that have at least one dimension with components smaller than 100 nm. In order to discover and make use of the advantageous qualities that result from these dimensions, nanotechnology is the science that deals with matter at the molecular and atomic levels and studies matter at the nanoscale level. Over the past few years, there has been a notable growth in the quantity of dental nanomaterials. There are numerous practical dental nanomaterials that are being studied. It has been demonstrated that nanoparticles are more effective than conventional materials and possess greater surface chemistry and bonding abilities. Additionally encouraging are their antibacterial properties, which are useful in numerous medical treatments but especially in endodontics. Nanomaterials are a helpful tool in dental clinics for a number of procedures due to their versatility, such as pulp regeneration, medication administration, root repair, Obturation, filling, and cleansing of the canals. By combining the fields of biotechnology and nanomaterials, nanomaterials have the potential to revolutionize oral health by offering diagnostic and preventative tools as well as the ability to repair damaged teeth. Nanomaterials are frequently employed in restorative dentistry to create coating materials, bio-ceramics, bonding agents, endodontic sealants, and nanocomposite resins. So this review paper for demonstrates types, potential application of nanoparticles in endodontic treatment.

Introduction:

Nano means "midget" in Greek. The term "nanoparticles" refers to a factor of 10−9, or one billionth on the American scale. Since it is hard for the human brain to envision such a small number, analogies have been shown to be able to understand the nanoscale. For example, the quotient of a meter (m) to a nanometer (nm) is roughly equal to the diameter of the earth and a hazelnut. In a second, a fingernail's length increases to roughly one nanometer (1). The science that works with molecules and atoms at the molecular level is called nanotechnology. To find and utilize the beneficial qualities that come from components at the nanoscale level, researchers have looked at a variety of industries. It was N. Taniguchi who first used the word nano- in 1974 at Tokyo Science University (2). The distinct physical characteristic of the nanoparticle is its high surface to core ratio, meaning that there are more atoms on the surface than in the core due to the surface having more unbound particles, which increases surface energy and more receptive to the opposite (3). A decrease in the melting point of nanomaterials is caused by a larger surface-to-volume ratio, with particular emphasis on prosthodontics for cast post and fabrications of metal crowns. Because of their high surface-to-volume ratio, the nanoparticles are easily rearranged into several configurations, which makes them suitable for a wide range of dental applications (4). One of the most modern innovations of the recent past is nanotechnology (5).The idea and definition of a nanomaterial have been made public in accordance with the European Commission's recommendation, and they relate to the origin, formation, form, and size distribution and particle size (6). Two primary approaches are used in the synthesis of nanomaterials: the top-down approach reduces the majority of the material to nano-metric measurements by a variety of techniques, while the bottom-up approach groups individual atoms together(7) Endodontics' main goal is to eradicate microorganisms that create biofilms. Nanotechnology will transform dentistry in the future, particularly in endodontics, as it has the enormous potential to have a significant impact on human health and welfare (8).

1. History and Development of Nanotechnology:

The theory of nanotechnology was first created by Dr. Richard Feynman (9), and he is regarding the modern technology but Taniguchi et al.(10) explain the meaning of this technology as many modifications of materials such as cracking, deformation division, and rebound brought on by an atom or molecule (11). Dr. Sumio Lijima first proposed the idea of carbon nanotubes in 1991(5). The term "nano-dentistry" was first used in 2000 by Dr. Freitas Jr. He created dentifrobots, or robots inside dentrifices, and invented nanomaterials and nanorobots. He also assisted in the regeneration of dentition. At first, all of these concepts were written off as "science fiction" and were thought to be impractical, but in the present day, doctors are beginning to acknowledge them (12).

2. Synthesis and Processing of Nanomaterials:

There are two types of methods for developing nanostructures: top-down and bottom-up. These two approaches differ from one another in terms of cost, product quality, and process speed. Within the using a bottom-up methodology, the nanostructures are constructed from the bottom up by controlling the self-assembly of atoms and molecules in nanoscale dimensions using chemical and physical techniques(13). The breakdown of bulk materials into nanostructured particles by the use of recently discovered processes like lithography or precision engineering is referred to as the "top-down method"(11). Functional method and bio mimic approach mean creating new materials mimicking natural matters (14).

Nanostructured materials have drawn more interest in recent years because of their potential uses in a variety of medical sectors, including therapy and diagnostics. This potential stems from the Nano-particles distinct chemical, biological, and physical properties linked to their large specific surface area as well as their quantum phenomena. Because the atoms available on their surface are less stable than those in bulk materials, their behavior differs greatly from bulk materials. This is because the surface atoms have fewer neighbors, which will result in less coordination and unfulfilled bonds. The delocalization of electrons resulting in quantum confinement effects is the other reason(15)(16).

3.Classification of Nanoparticles:
Nano-particles can be classified to natural and synthetic materials due to their composition, it has regular structures and molecules in unbound phase, in which about half of the molecules have the molecular level its size not exceed of (100nm)(17), according to shape of materials can be spherical, tubular, plate shape and rode shape (18). Another way of classification for nanomaterials according to their dimensions as shown in Figure(1); either zero (such as fullerenes), one (such as thin surface coatings), two (such as graphene), or three dimensions (such as composite nanomaterials) (8):
naturally occurring nano-particle subdivided into:

***Inorganic or Metallic nano-partiles:**
1) Silver nanoparticles (AgNano-particles): AgNano-particles has a broad spectrum of anti-bacterial property for oral micro-organisms, such as resistant to microspecies (19), so its use as intra-canal irritants or medicaments to sterilize or disinfect canals of radicular system during treatment of endodontic. The mechanism of anti-bacterial effect of silver nanoparticles is due to interaction with the sulfhydryl group of proteins and DNA, the unwinding of DNA, and interfacial with the syntheses of cell wall and cell division (20), so silver nanoparticles can eliminate the smear layer, in line with eliminating E faecalis from the root canal system (21).

2) Magnesium-containing nanoparticles (Mg-Nano-particles): Such as magnesium halogen-containing nanoparticles, Magnesium-oxide, hydroxide, are different forms of this type. The ability of Magnesium halogen-containing nanoparticles is to penetrate the bacterial cell wall, leading to the disturbance in the potential of membrane, inhibiting the activity of specific enzymes in cell. The bacterio-cidal property of magnesium oxide nanoparticles is related to reactive oxygen species production on the surface of bacterial cell and its activity against to E. faecalis, S. aureus, and Candida albicans (22)(23).

3) Zinc oxide nanoparticles (ZnO-Nano-particles): Its possess high effect of anti-bacterial property and killing to the bacterial cells in environment with a higher pH (24)(25). The anti-bacterial properties of these types of nanoparticles are due to the elevation the cell wall permeability of bacteria, that leads to the elaborate amount of cytoplasmic content, and cell killing occurs (26). In the study of Kishan et al. concluded that zinc oxide nano-particles can stop the growth of E. faecalis in the biofilm of oral cavity. Combination between zinc oxide nano-particles and resin-based sealer ensures a (95%) depression in E. faecalis adhesion to dentinal wall and biofilm production (27).

***Organic or Polymeric Nano-materials**
1) Chitosan nanoparticle: Chitosan is commonly utilized in different medical fields applications, especially for skin substitutes and management of wound, due to many specific properties such as biodegradability, hydrophilicity, biocompatibility, and a broad-spectrum antimicrobial against gram-negative and positive bacteria and also fungi (28). Mechanism of anti-microbial property du to electrostatic interaction when positive charge chitosan touch negative charge of bacterial cell membrane, this ionic differences lead to increased permeability of cell wall, leakage of intracellular content and disintegration of bacterial cell (29). Chitosan benefits include (30):
1. It does not harm mammalian cells in any way.
2. A color that blends in with the tooth structure.
3. Economical.
4. Accessibility.

2) Bioactive glass: Bioactive glass (BAG) consist of a complex mixture of (24%) Na_2O, (45%) SiO_2, , (6%) $P2O_5$ and (24.5%) CaO. BAG has been used to enhance the disinfection and sterilization of the root canal system due to its broad-spectrum antimicrobial effects. However, the BAG was less activity than calcium hydroxide ($Ca(OH)_2$) in microbial growth stopping. The nano-particulate production of bioactive glass (45S5) showed superior anti-microbial efficient due to high quantity release of alkaline species (31). In the study of Marending et al. did a comparison between nano-particulate bioactive glass 45S5 and Ca(OH)2 to treat anterior teeth immature apex with trauma as intra-canal medicament ,who concluded that Ca(OH)2 produced a (35%) decrease in mean values dentin flexural strength, but bioactive glass (45S5) has reduction a(20%) in the same mean value and superiority over Ca(OH)2(32).

Application of Nano-particles in Endodontic treatment:
Almost every area of research and development has been impacted by nanotechnology. This technology's immense potential has also influenced the fields of medicine and dentistry. Nevertheless, since the majority of the problems in endodontics (microorganisms and dentin) are nano-sized, it is obvious that the field will continue to move in this direction. The field of dentistry is heading toward a bright future thanks to the advent of nano-endodontics. The application of nano-particles in endodontic treatment (33) shown in figure (2) and as followings:

1-Using of Nanoparticles as Endodontic Irrigants: The key point of endodontic disinfection is irrigation because it can inactivate, reach and removed bacteria that attached to the walls of dentin which not reached by mechanical instrumentation so irrigation indicated for both the removal and killing of microbes and also eliminate remnants and debris of dentine and necrotic tissues (34). In an ideal properties of irrigants should be nontoxic or low-toxic with ability of antimicrobial effect and less adverse reactions if inadvertent extrusion which such occur with sodium hypo chloride solution (35). Given the shortcomings of traditional irrigants, nanoparticles have been used to create innovative irrigation materials. Nanoparticles of chitosan have shown increased antibiofilm effectiveness and the capacity to stop the bacterial endotoxins. These tiny particles lead to an organized release of singlet oxygen species indicates increased bacterial breakdown. They are recommended to be used as a last rinse while root irrigation because they do not cause harm to eukaryotic cells (36)(5).
Nano-particles have bright future as alternatives irrigants , especially Ag nanoparticles (37), because it have a more surface area to volume ratio which enhances the interactions with microbes, and have a special sizes and shapes that increase their anti-microbial actions (38). Ag Nano-Particles have biocompatibility with human tissues, and highly toxic effect for microbes, especially E. faecalis (39,40), also Ag Nano-Particles can penetrate and reach the apical part of the root canal system when used as irrigants in endodontic treatments (41). Because Size of Ag Nano-Particles is (1 to 2 nm in size) it have ability to penetrate the smear layer on radicular dentine produced barrier film on the surface of surface, which can decrease the risk of bacterial invasion (42), without any harmful effect on physical structure of the radicular dentine (43,44).

2-Using of Nanoparticles as Obturating Materials: Obturating materials have an important role in endodontic treatment to fill the root canal system, The ideal filler material must have the following qualities in order to be utilized in endodontic treatment: it must be biocompatible with the tissue, promote the regeneration of damaged cells or at least help it, be easy to remove from the canals and adapt to them, and have antimicrobial activity, water insolubility, dimensional stability over time, adhesion to the canal walls, and good, features of handling and flow, radiopacity, imperviousness, and non-porosity,Gutta-percha is the commonly used as obturating material. Although its commonly use (8). Gutta-percha has several disadvantages, especially the absence of anti-microbial properties (45). So there is a forward direction in incorporating Nano-Particles into gutta-percha points to decrease its disadvantages, such as nano-diamond gutta-percha composition can decrease the dangerous of re-infection and enhance the mechanical properties and strength of gutta-percha points, so enhancing their clinical manageability (46). Regarding the lack of true adhesion of Gutta-Percha and consequently microleakage, root canal reinfection, and not enough completed mechanical properties, attempts were made to use additives to improve these capacities. Researchers have investigated the medical activity of gutta-percha cones containing different substances including calcium hydroxide bioceramic, resin, iodoform, zinc oxide, nonthermal plasma-argon, and oxygen plasma chlorhexidine, and cetylpyridinium chloride alone or used in combination (47) . Incorporating nano-diamond amoxicillin conjugates with gutta-perch, the size of nano-diamond particles is (4 to 6 nm) have adsorb antibiotics and antibacterial properties, possibility the elimination of persistent microbes . Ag Nano-Particles can be introduced into gutta-percha to produce silver ions releasing, that have antimicrobial properties. Different types of techniques have been produced for coating Ag Nano-Particles onto gutta-percha points, with one method that involving the use of a plasticizer (48). Ag Nano-Particles-coated points have less toxicity to the cells of human body and good biocompatibility with it, and it has antimicrobial effect against C. albicans and also against several bacteria, including E. faecalis, S. aureus, and E. coli (49).

3-Using of nanoparticles as Endodontic Sealers: Making the seal impermeable is one of an endodontic sealer's most important tasks. This can be achieved by repairing any small dents and imperfections that could exist between the stem filling material and the root canal wall. A polymicrobial nature characterizes root canal infection, with E. faecalis being one of the main culprits due to the production of many proteolytic enzymes and harmful aggregation components, endodontic infections that recur are caused by E. faecalis because of its resistance to calcium hydroxide alone (50). Furthermore, in the event that the microbes persist the sealant then satisfies the microbiological control in the tubules or lateral canals. Researches have demonstrated that, despite the use of root canals, 40–60% of the germs survived. Considering various NaOCL concentrations in the chemo-mechanical root canal cleaning technique (8). In a study by Kishen et al., obturating sealers were treated with chitosan and zinc oxide nanoparticles. The outcomes shown that these Nano-particles suppressed bacterial breach in the canal that resulted in a resolution that adding these Nano-particles to the sealers produced a favorable result (5). Endo Sequence bio-ceramic sealer It was created lately and is made up of calcium phosphate, calcium hydroxide, calcium silicates, zirconia, and a thickening agent. The properties of nanoparticles enhanced physical characteristics. A structure of nanocomposites of calcium silicate and hydroxyapatite generated during. The root canal's hydration reaction. This process of hydration the setting time is determined by the water's availability and in too dried canals, the setting time may need to be extended. Materials can be delivered from 0.012 with the use of nano-sized particles tiny needles and adjust to uneven dentin surfaces outstanding provide dimensional stability and seal (51)(52). Addition of silver nano-particles to endodontic sealer is benefit as anti-microbial effect because AgNano-particles can trigger a breakdown of chemical equilibrium in the bacterial cell, they are unique among antibacterial nanoparticles, AgNano-particles must be stabilized because it has been observed that they produce ROS, which causes membrane proteins and lipids to degrade (53). Thus, stabilizing AgNano-particles is necessary, because carbon nanodots are bioactive and can scavenge ROS, they can replace AgNano-particles and prevent the production of reactive oxygen species (ROS) (54). This is accomplished by the carbon nanodots' surface producing -COOH and -OH groups. By creating bonds with the AgNano-particles, these groups stabilize the AgNano-particles (55).

4-Using of Nanoparticles as Retro-Filling and Root Repair Materials: The importance of installing root-end fillings during periapical surgery has been highlighted by a number of studies (56). Mineral trioxide aggregate (MTA) is still the most popular and is regarded as the gold standard for comparison with recently developed materials (57). But MTA has disadvantages as well, such as handling challenges, a long setup time, high cost, and a lack of characteristics that are antibacterial and soluble in PH that is acidic (58). According to reports, adding Ag Nano-particles shortens the MTA setting time, speeds up the hydration of silicates, and may increase the material's usefulness (59). Additionally, it is stated to overcome MTAs and enhance dimensional stability, which is essential for healthy tissue regeneration. It also works well as a radiopacifier. reduced radiopacity for more lucid radiography images (60). Bismuth lipophilic Nano-particles have significantly improved MTA's antibacterial and antibiofilm capabilities without sacrificing any other properties. Physical characteristics, suggesting improved clinical results (61). The porous structure of silver-zeolite Nano-particles, which releases silver ions over time, enhances MTA's antibacterial capabilities. against a variety of microbes (62)(63).

Advantages and Disadvantages of Nanotechnology:

1- Advantages of Nanotechnology:

1. Excellent handling qualities for all Nano-dental products, as well as superior hardness, flexural strength, modulus of elasticity, translucency, and durability of Nano-dental materials.
2. More rapid and precise diagnosis of oral diseases using portable diagnostic equipment.
3. Shorter treatment duration combined with quicker healing capabilities.
4. Lower rates of morbidity and death therefore linked to specific oral illnesses.
5. Better aesthetics.
6. Patients will attend dental clinics less frequently, and practitioners will feel less worn out.
7. Clearly superior results from the therapeutic methods.
8. Cost-effective (64).

2-Disadvantages of Nanotechnology:

1. There are many moral dilemmas to resolve (social acceptance is important).
2. The environment and humans are both harmed by the toxicity linked to the nanoparticles.
3. The subsequent irreversible loss of genetic information that was necessary to improve the prospects for nanotechnology in general and nano dentistry in particular.
4. High cost.

Conclusion:

The scientific community should embrace this new discipline with great responsibility because nanotechnology is a developing science. Regarding endodontics, Nanotechnology is expected to enhance not just the mechanical characteristics, but also significantly enhance the biological characteristics of a substance. It's not too far off. that nano dentistry will be successful in preserving almost flawless oral health using nanorobotics and nanomaterials as well as biotechnology.

Author Contribution: Emad Farhan: study conception and design and analysis and interpretation of results, Amani Abduljabar: data collection and manuscript preparation

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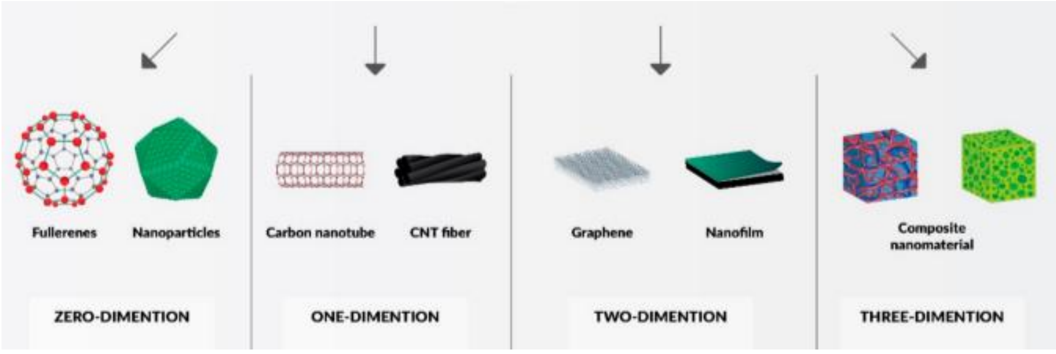

Figure(1): represent dimensional division of nano-p articles.

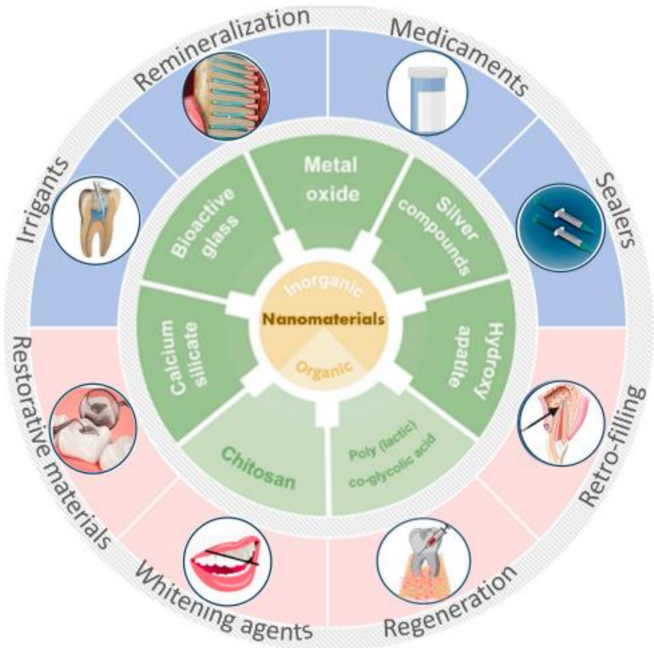

Figure (2): Using of nano-particles in endodontic treatment (34).

References

(1) Klaus, D. Jandt, T. and David, C. Watts. Nanotechnology in dentistry: Present and future perspectives on dental nanomaterials. Dental Materials. 2020;36(11):1365-1378.

(2) Solanke, I.A. Ajayi, D. Arigbede, A. Nanotechnology and its application in dentistry. Ann. Med. Health Sci. Res. 2014; 4(1), 171–177.

(3) Binns, C. An introduction to nanoscience and nanotechnology, Nano
Ethics 1st ed. John Wiley & Sons. 2010 :1-13.

(4) Verma, S., Chandra, A., Jena, A. and Sharan, J. Nanotechnology in Endodontics: A Hope or Hype. Trends Biomater. Artif. Organs, 2021;35(2): 190-202.

(5) Raura, N. Garg, A. Arora, A. Roma, M. Nanoparticle technology and its implications in endodontics: A review. Biomater. Res. 2020; 2(4): 21-29.

(6) Neoh, G.K. Li, M. Kang, E.T. Characterization of nanomaterials/nanoparticles. In Nanotechnology in Endodontics: Current andPotential Clinical Applications; Kishen, A., Ed.; Springer International Publishing Switzerland: Cham, Switzerland, 2015;1: 23–44.

(7) Foong, L.K., Foroughi, M.M., Mirhosseini, A.F., et al. Applications of nano-materials in diverse dentistry regimes .RSC Adv. 2020; 10:15430-60.

(8) Zakrzewski,W. , Dobrzy ´nski, M., Zawadzka-Knefel, A., Luboja ´nski , A., Dobrzy ´nski , W.,Janecki, M., Kurek, K., Szymonowicz, M., Wiglusz, R. and Rybak, Z.

Nanomaterials Application in Endodontics. Materials 2021, 14, 5296.
(9) Feynman, R.P. There's Plenty of Room at the Bottom. Eng. Sci. Mag. 1960, 23, 22–36.
(10)Taniguchi, N. Arakawa, C. Kobayashi, T. On the basic concept of nanotechnology. In Proceedings of the International Conference on Production Engineering, Japan Society of Precision Engineering, Tokyo, Japan,1974; pp. 26–29.
(11)Bayda, S. Adeel, M. Tuccinardi, T. Cordani, M. Rizzolio, F. The History of Nanoscience and Nanotechnology: From Chemical–Physical Applications to Nanomedicine. Molecules 2020, 25, 112.
(12) Jeevanandam, J., Barhoum, A., Chan, Y.S., Dufresne, A., Danquah, M.K. Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations. Beilstein J Nanotechnol. 2018;9(1):1050–74.
(13) Iqbal, P., Preece, J.A. and Mendes, P.M. Nanotechnology: The "Top-Down" and "Bottom-Up" Approaches. Supramolar Chemistry: Fro Molecules to Nanomaterials; John Wiley & Sons Ltd: Hoboken, NJ, USA, 2012.
(14) Sreenivasalu, P., Dora, C., Swami, R., Jasthi, V., Shiroorkar, P., Nagaraja, S., Asdaq, S. and Anwer, M. Nanomaterials in Dentistry: Current Applications and Future Scope. Nanomaterials 2022, 12, 1676.
(15) Buzea, C. Pacheco, I.I. Robbie, K. Nanomaterials and nanoparticles: Sources and toxicity. Biointerphases 2007, 2: 17–71.
(16) Roduner, E. Size matters: Why nanomaterials are different. Chem. Soc. Rev. 2006, 35, 583–592.
(17) Zakrzewski, W. Dobrzynski, M. Dobrzynski, W. Zawadzka-Knefel, A. Janecki, M. Kurek, K. Lubojanski, A. Szymonowicz, M. Rybak, Z. Wiglusz, R.J. Nanomaterials Application in Orthodontics. Nanomaterials 2021, 11, 337.
(18) Veerapandian, M. Yun, K. Functionalization of biomolecules on nanoparticles: Specialized for antibacterial applications.Appl. Microbiol. Biotechnol. 2011, 90, 1655–1667.
(19) Egger, S., Lehmann, R.P., Height, M.J., M. Loessner, M.J. and Schuppler, M. Antimicrobial properties of a novel silver-silica nanocomposite material, Appl Environ Microbiol., 2009;5(9):2973–2976.
(20) Alshareef, A., Laird, K., Cross, R. Shape-dependent antibacterial activity of silver nanoparticles on Escherichia.coli and Enterococcus.faecium bacterium, Appl Surf Sci., 2017;424 (3): 310-315.
(21) Gonzalez-Luna, P.I., Martinez-Castanon, G.A., Zavala-Alonso, N.V., Patino-Marin, N., Nino-Martinez, N. and Moran-Martinez, J. Bactericide Effect of Silver Nanoparticles as a Final Irrigation Agent in Endodontics on Enterococcus faecalis: An Ex Vivo Study, Journal of Nanomaterial., 2016; (1): 1-7.
(22) Pan, X., Wang, Y., Chen, Z., Pan, D., Cheng, Y., Liu, Z. et al. Investigation of antibacterial activity and related mechanism of a series if nano-Mg(OH)2, ACS Applied Mater Inter., 2013;5(3):1137-1142.
(23) Monzavi, A., Eshraghi, S., Hashemian, R. and Momen-Heravi, F. In vitro and ex vivo antimicrobial efficacy of nano-MgO in the elimination ofendodontic pathogens, Clin Oral Investig., 2015;19(2):349-356.
(24) Song, W., Zhang, J., Guo, J. Zhang, J., Ding, F., Li , L. et al. Role of the dissolved zinc ion and reactive oxygen species in cytotoxicity of ZnO nanoparticles, Toxicol Lett., 2010;199(3):389-397.
(25) Huang, Z., Zheng, X., Yan, D., Yin, G., Liao, X., Kang, Y. et al. Toxicological effect of ZnO nanoparticles based on bacteria, Langmuir. 2008;24(8):4140-4144.
(26) A. Sirelkhatim, S. Mahmud, A. Seeni et al. Review on Zinc Oxide Nanoparticles: Antibacterial Activity and Toxicity Mechanism, Nanomicro Lett., 2015; 7(3):219-242.
(27) A. Kishen, Z. Shi, A. Shrestha, K. G. Neoh, An investigation on the antibacterial and antibiofilm efficacy of cationic nanoparticulates for root canal disinfection, J Endod., 2008;34(12):1515-1520.
(28) Muzzarelli, R. Tarsi, R., Filippini, O., Giovanetti, E., Biagini, G. and Varaldo, B.E. Antimicrobial properties of N-carboxybutyl chitosan Antimicrob Agents Chemother., 1990;34(10):2019-2023.
(29) Rabea, E.I., Badawy, M.E., Stevens, C.V., Smagghe, G. and Steurbaut, W.Chitosan as antimicrobial agent: applications and mode of action. Biomacromolecules., 2003; 4(6):1457-1465.
(30) Alenazy MS, Mosadomi HA, Al-Nazhan S, Rayyan MR. Clinical considerations of nanobiomaterials in endodontics: A systematic review. Saudi Endod J. 2018;8(3):163–9.
(31) Waltimo, T., Mohn, D., Paqué, F., Brunner, J.T., Stark, W.J. and Imfeld, I. Fine-tuning of bioactive glass for root canal disinfection, J Dent Res., 2009;88(3):235-238.
(32) Marending, M., Stark, W.J., Brunner, T.J., Fischer, J. and Zehnder, M.Comparative assessment of time-related bioactive glass and calcium hydroxide effects on mechanical properties of human root dentin, Dent Traumatol., 2009;25(1):126-129.
(33) Farzaneh Afkhami, Yuan Chen, Laurence J. Walsh, Ove A. Peters, Chun Xu. Application of Nanomaterials in Endodontics. BME Front. 2024;5:0043.
(34) Tsotsis, P., Dunlap, C., Scott, R., Arias, A., Peters, O.A. A survey of current trends in root canal treatment: Access cavity design and cleaning and shaping practices. Aust. Endod. J. 2021;47(1):27–33.
(35) Hu, C., Wang, L-L, Lin, Y-Q., Liang, H-M., Zhou, S-Y., Zheng, F., Feng, X.L., Rui, Y.Y., Shao, L.Q. Nanoparticles for the treatment of oral biofilms: Current state, mechanisms, influencing factors, and prospects. Adv. Healthc. Mater. 2019;8(24):1901301.
(36) Shrestha, A., Kishen, A. Antibiofilm efficacy of photosensitizer- functionalized bioactive nanoparticles on multispecies biofilm. J Endod. 2014;40(10):1604–10.
(37) Afkhami ,F., Forghan, P., Gutmann, J.L., Kishen, A. Silver nanoparticles and their therapeutic applications in endodontics: A narrative review. Pharmaceutics. 2023;15(3):715.
(38) Bhandi, S., Mehta, D., Mashyakhy, M., Chohan, H., Testarelli, L., Thomas, J., Dhillon, H., Raj, A.T., Madapusi Balaji, T., Varadarajan, S., et al. Antimicrobial efficacy of silver nanoparticles as root canal irrigant's: A systematic review. J. Clin. Med. 2021;10(6):1152.
(39) Nabavizadeh, M., Ghahramani, Y., Abbaszadegan, A., Jamshidzadeh, A., Jenabi, P., Makarempour, A. In vivo biocompatibility of an ionic liquid-protected silver

nanoparticle solution as root canal irrigant. Iran Endod J. 2018;13(3):293–298.
(40) Al-Fhham, B.M., Al-Haidar, A.H.M. Evaluation of the antibacterial efficacy of silver nanoparticles as an irrigant against E. faecalisin vitro study. J Res Med Dent Sci. 2019;7(4):21–27.
(41) Topala, F., Nica, L-M., Boariu, M., Negrutiu, M.L., Sinescu, C., Marinescu, A., Cirligeriu, L., Stratul, S.I., Rusu, D., Chincia, R., et al. En-face optical coherence tomography analysis of gold and silver nanoparticles in endodontic irrigating solutions: An in vitro study. Exp. Ther. Med. 2021;22(3):992.
(42) Razumova, S., Brago, A., Serebrov, D., Barakat, H., Kozlova, Y., Howijieh, A., Guryeva, Z., Enina, Y., Troitskiy, V. The application of nano silver argitos as a final root canal irrigation for the treatment of pulpitis and apical periodontitis. In vitro study. Nanomaterials. 2022;12(2):248.
(43) Umeda Suzuki, T.Y., Gallego, J., Assuncao, W.G., Fraga Briso, A.L., dos Santos, P.H. Influence of silver nanoparticle solution on the mechanical properties of resin cements and intrarradicular dentin. PLOS ONE. 2019;14(6):e0217750.
(44) Suzuki, T..YU., Pereira, M.A, Gomes-Filho, J.E., Wang, L., Assuncao, W.G., dos Santos PH. Do irrigation solutions influence the bond interface between glass fiber posts and dentin? Braz. Dent. J.. 2019;30(2):106–116.
(45) Liao, S.C., Wang, H.H., Hsu, Y.H., Huang, H.M., Gutmann, J.L., Hsieh, S.C. The investigation of thermal behaviour and physical properties of several types of contemporary guttapercha points. Int. Endod. J. 2021;54(11):2125–2132.
(46) Vishwanath, V.; Rao, H. Gutta-percha in—A comprehensive review of material science. J. Conserv. Dent. 2019, 22, 216.
(47) Lee D-K, Kim SV, Limansubroto AN, Yen A, Soundia A, Wang C-Y, Shi W, Hong C, Tetradis S, Kim Y, et al. Nanodiamond–gutta percha composite biomaterials for root canal therapy. ACS Nano. 2015;9(11):11490–11501.
(48) Mohan, A., Dipallini, S., Lata, S., Mohanty, S., Pradhan, P., Patel, P., Makkar, H., Verma, S.K. Oxidative stress induced antimicrobial efficacy of chitosan and silver nanoparticles coated Guttapercha for endodontic applications. Mater Today Chem. 2020;17:100-299.
(49) Mozayeni, M.A., Dianat, O., Tahvildari, S., Mozayani, M., Paymanpour, P. Subcutaneous reaction of rat tissues to nanosilver coated gutta-percha. Iran Endod J. 2017;12(2):157–161.
(50) D'Ercole, S., Di Fermo, P., Di Giulio, M., Di Lodovico, S., Di Campli, E., Scarano, A., et al. Near-infrared NIR irradiation and sodium hypochlorite: An efficacious association to counteract the E. faecalisbiofilm in endodontic infections. J. Photochem. Photobiol. B. 2020;210:111989.
(51) Chole, D., Khan, I., Kundoor, S., Bakle, S., Gandhi, N., Deshpande, R., et al.
Nanotechnology: Conservative Dentistry and Endodontics. IOSR J Dent Med Sci (IOSR-JDMS) . 2017;16(4):102–7.
(52)Kasha, P., Krishna, N.V., Prasad, S.D., Chandra Shekar, M., SunilKumar, C., SunilKumar, S. Role of nanotechnology in endodontics. IP Indian J Conserv Endod 2022;7(1):1-5.
(53) Salleh, A., Naomi, R., Utami, N.D., Mohammad, A.W., Mahmoudi, E., Mustafa, N., et al. The potential of silver nanoparticles for antiviral and antibacterial applications: a mechanism of action. Nanomater. 2020;10(8):1566.
(54) Das, B., Dadhich, P., Pal, P., Dutta, J., Srivas, P.K., Dutta, A., et al. Doping of carbon nanodots for saving cells from silver nanotoxicity: A study on recovering osteogenic differentiation potential. Toxicol. In Vitro. 2019;57:81–95.
(55) Ali, T.W., Gul, H., Fareed, M.A., Tabassum, S., Mir, S.R., Afzaal, A., et al. (2024) Biochemical properties of novel Carbon nanodot-stabilized silver nanoparticles enriched calcium hydroxide endodontic sealer. PLoS ONE 19(7): 0303808.
(56) Uğur Aydın, Z., Toptaş, O., Göller Bulut, D., Akay, N., Kara, T., Akbulut, N. Effects of root-end filling on the fractal dimension of the periapical bone after periapical surgery: Retrospective study. Clin. Oral Investig. 2019;23:3645–3651.
(57) Torabinejad, M., Parirokh, M., Dummer, P.M. Mineral trioxide aggregate and other bioactive endodontic cements: An updated overview–part II: Other clinical applications and complications. Int. Endod. J. 2018;51(3):284–317.
(58) Suhag, A., Chhikara, N., Pillania, A., Yadav, P. Root end filling materials: A review. Int J Appl Dent Sci. 2018;4(2): 320–323.
(59) Vazquez-Garcia, F., Tanomaru-Filho, M., Chávez-Andrade, G.M., Bosso-Martelo, R., Basso-Bernardi, M.I., Guerreiro-Tanomaru, J.M., Paulista, U.E., Brazil, Universidade Federal da Bahia, Brazil, Universidade de São Paulo, Brazil. Effect of silver nanoparticles on physicochemical and antibacterial properties of calcium silicate cements. Braz. Dent. J. 2016;27:508–514.
(60) Mendes, M.S., Resende, L.D., Pinto, C.A., Raldi, D.P., Cardoso, F.G., Habitante, S.M. Radiopacity of mineral trioxide aggregate with and without inclusion of silver nanoparticles. J. Contemp. Dent. Pract. 2017;18(6):448–451.
(61) Hernandez-Delgadillo, R., Del Angel-Mosqueda, C., Solís-Soto, J.M., Munguia-Moreno, S., Pineda-Aguilar, N., Sánchez-Nájera, R.I., Shankararaman, C., Cabral-Romero, C. Antimicrobial and antibiofilm activities of MTA supplemented with bismuth lipophilic nanoparticles. Dent. Mater. J. 2017;36(4):503–510.
(62) Çinar, Ç., Odabaş, M., Gürel, M.A., Baldağ, I. The effects of incorporation of silver-zeolite on selected properties of mineral trioxide aggregate. Dent. Mater. J. 2013;32(6): 872–876.
(63) Rodríguez, C.G., Cepeda, M.A.A.N., Arana, H.L.M., Lopez, J.F.G., Zavala, C.E., Cuevas, R.P., Molina, B.C., Soto, S. Current and future options for dental pulp regeneration. Int J Appl Dental Sci. 2023;9(1):178–182.
(64) Tafti, F., Savant, S., Saraf, T., Pinge, S., Thorat, R., Sharma, V. Hazards Associated With Nanotechnology in Clinical Dentistry. Cureus. 2023;15(10):46978.