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Nanotechnology Implementation as Root Canal Sealer

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ABSTRACT

The application of nanotechnology is becoming increasingly prevalent in the field of dentistry. Specifically, in root canal treatment, the expulsion of microbes remains a challenge often leading to failure of the procedure. The use of sealer is an effective method to dispose of microbes, but the structure of root canal which features dentinal tubules ranging from micro to nano size underscores the need for nanoparticle sealer. Therefore, this review aimed to evaluate the implementation of nanomaterials as root canal sealer. The results showed that nanoparticle sealer increased the apical sealing ability of root canal obturation material. The concept of using nanoparticles in endodontics as a new treatment efficacy against the hidden microbes in dentinal tubules appeared to be a promising approach. The development of nanotechnology could be used to improve the ability of sealer to penetrate dentinal tubules to achieve successful root canal treatment.

Keywords: Nanomaterial, Sealer, Root Canal Treatment

ABSTRAK

Sudah sejak lama, teknologi nano telah digunakan dalam bidang kedokteran gigi. Dalam perawatan saluran akar, pengusiran mikroba di dalam sistem saluran akar masih merupakan dampak dari kegagalan perawatan. Penggunaan sealer pada perawatan saluran akar merupakan salah satu cara untuk membuang mikroba dari dalam saluran akar, namun struktur saluran akar yang memiliki tubules dentin dengan ukuran mulai dari mikron hingga nano menjadi salah satu alasan mengapa diperlukan sealer nanopartikel. Tujuan dari tinjauan ini adalah untuk mengetahui implementasi material nano sebagai sealer saluran akar. Beberapa penelitian melaporkan bahwa sealer dengan nanopartikel dapat meningkatkan kemampuan penyegelan apikal dari bahan obturasi saluran akar. Konsep penggunaan nanopartikel dalam endodontik sebagai khasiat perawatan baru terhadap mikroba tersembunyi dalam tubules dentin muncul sebagai dampak yang menjanjikan. Perkembangan nanoteknologi dalam endodontik dapat digunakan sebagai salah satu cara untuk meningkatkan kemampuan sealer dalam menembus tubules dentin untuk mencapai keberhasilan perawatan saluran akar.

Kata kunci: Nanomaterial, Sealer, Perawatan Saluran Akar

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1. Introduction

Root filling is the concluding phase in the traditional triad of endodontic procedures, comprising instrumentation, cleansing, and obturation. The main objective of endodontic treatment is to effectively remove all debris from root canal system, eliminate pathogenic bacteria, and thoroughly fill canal space. The process of filling or obturating canal space is of significant importance in preventing the infiltration of microorganisms from the oral environment, minimizing the risk of coronal leakage, and preventing the collection of fluids. Consequently, the filling materials must have optimal sealing, adaptability, and adhesion to root canal wall [1-4].

An important aspect that significantly affects a proper seal is gutta-percha backfill shrinkage and the subsequent formation of irregularities and voids. Therefore, an appropriate sealer needs to possess the capability of deeply infiltrating dentinal tubules, effectively filling any abnormalities, obstructing liquid infiltration between the gutta-percha and dentinal walls, as well as resistance against the occurrence of microleakage from external sources in relation to filling materials [1,2,5,6].

The ineffectiveness of conventional antimicrobial carriers in eliminating deep bacteria infections can be attributed to the limited ability to infiltrate, penetrate, and infect dentinal tubules. The ability of an endodontic material to penetrate dentinal tubules is influenced by various parameters, including the dimensions of tubules, the size of particles, and the substance's setting reaction. The range of diameters observed in dentinal tubules at the pulpal wall is between 2.0 and 3.2 μm, with the minimum size being approximately 500 nm. Only materials with a particle size smaller than the diameter of tubules have infiltrating ability [1,4,7].

The field of dentistry has experienced significant advancements in innovation during the past few decades, including the incorporation of nanotechnology [8], leading to an extensive range of medicinal applications. These include medication delivery systems, tissue regeneration methods, antibacterial treatments, gene transfection methods, and imaging technologies [9]. The discipline of nanotechnology, also known as molecular engineering, enables precise manipulation and management of materials at the nanoscale, in which at least one dimension is smaller than 100 nm in size. Consequently, these materials are referred to as nanomaterials[4,8,10-12].

The concept of nanodentistry entails the usage of nanomaterials and dental nanorobots in various fields of diagnosis and therapy, with the primary objective of enhancing overall oral health. In the field of endodontics, there is a concentrated effort towards the advancement of nanomaterials. The primary objectives of recent investigations are to optimize the efficacy of antimicrobial medicines, improve the mechanical properties of damaged dentin matrix, and promote tissue regeneration [8,10,11]. Therefore, this study aimed to present nanotechnology implementation as root canal sealer.

2. Literature Review

2.1. Dentinal structures

The mechanical properties of the tooth are related to the structure of dentin, which is composed of around 75% inorganic material, 20% organic matter, as well as approximately 5% water and other components. The synthesis and generation of dentin are performed by odontoblasts, responsible for major morphological characteristics, particularly dentinal tubules [13]. Tubules can be observed in two orientations on scanning electron microscopy (SEM) images, namely longitudinal and cross-sectional [13].

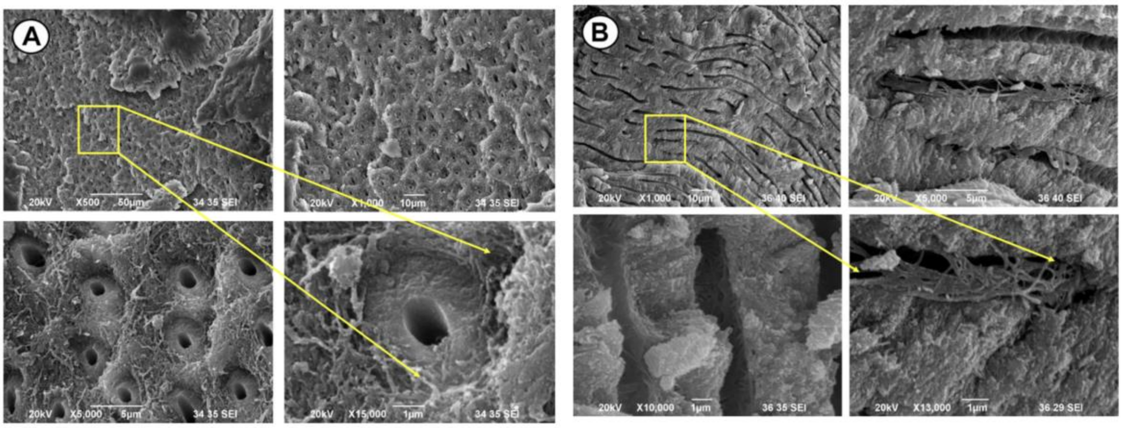

Figure 1. The provided images depict secondary electron (SE) photomicrographs of coronary dentin (A) and root dentin (B) at varying levels of magnification [13].

Tubules develop during the process of dentinogenesis around odontoblasts' processes. These structures form in the region located above the pulp chamber, traverse the entire width of dentin, and ultimately terminate at dentinoenamel junction (DEJ). The density of tubules is higher in proximity to the pulp, while the lumen decreases and the intertubular gaps rise near DEJ. The peritubular dentin forms a mineralized layer around each tubule. Furthermore, the intertubular dentin, which has less amount of mineralization, is located between tubules. The processes of the odontoblasts have extensive branching, giving rise to many lateral processes that form lateral canals, also known as canaliculi. The optical microscope's cross-sectional images show the presence of dentinal tubules with an S-shaped orientation [13].

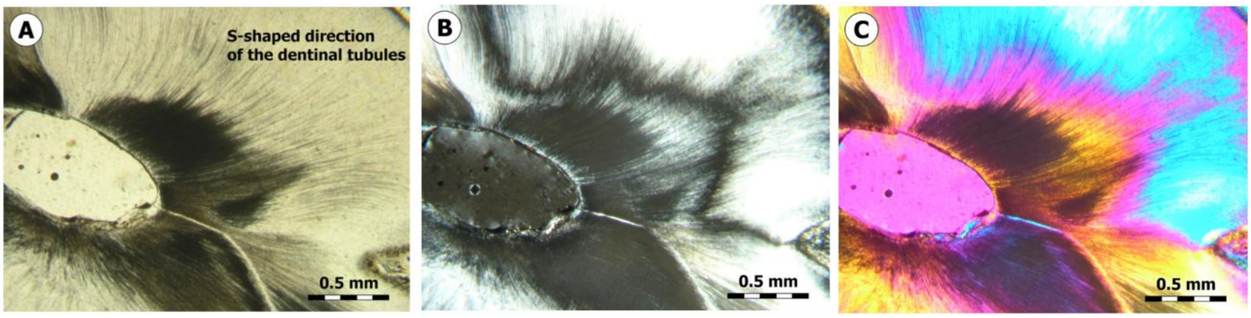

Figure 2. The provided images depict the structure of root dentin as observed by transmitted light photomicrographs. The images were captured using plane-polarized light with parallel Nicols (A), crossing Nicols (B), and a λ-plate compensator (C). The lumen of root canal is visible [13].

Giudice et al. (2015) reported that the average diameter of dentinal tubules in various areas had a range of variations. Specifically, the coronal, intermediate, and apical areas demonstrate a variation range between 6.43 and 2.44 µm, 6.64 and 1.7 µm, as well as 3.36 and 0.41 µm, respectively. In terms of tubular density, the average tubular density in the coronal third of canal is higher (46.798 ± 10.644 mm^2) compared to the middle (30.940 ± 7.651 mm^2). In the apical third, tubular density is similar to that of the coronal third, but with a smaller tubular diameter (1.731 μm) [14].

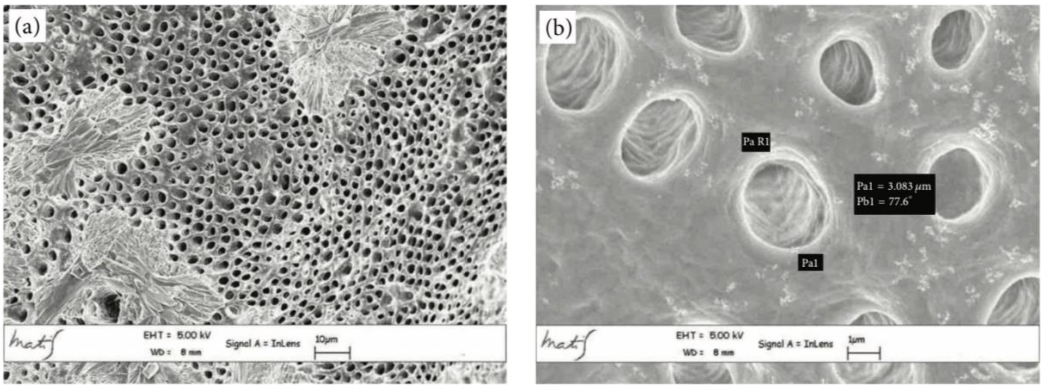

Figure 3. The coronal area metalized dentin specimens were examined using the Gemini Field Emission Scanning Electron Microscope (FEM-SEM) at a resolution of 1.7 μm and a pixel resolution of 3072 × 2304, with a magnification of 2500x. (A) 23000x (B) magnification: the presence of calcopherites [14].

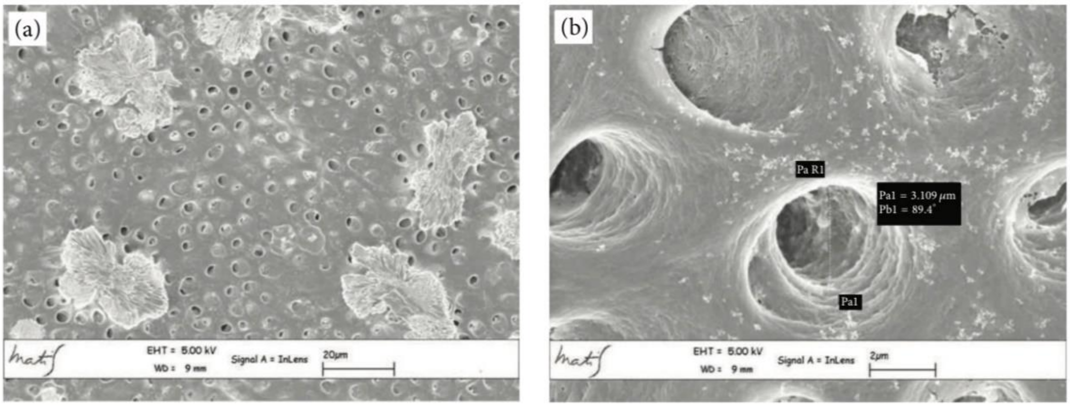

Figure 4. The middle area metalized dentin specimens were examined using the Gemini Field Emission Scanning Electron Microscope (FEM-SEM) at a resolution of 1.7 μm and a pixel resolution of 3072 × 2304, with a magnification of 2500x. A) 23000x (B) magnification: presence of calcospherites [14].

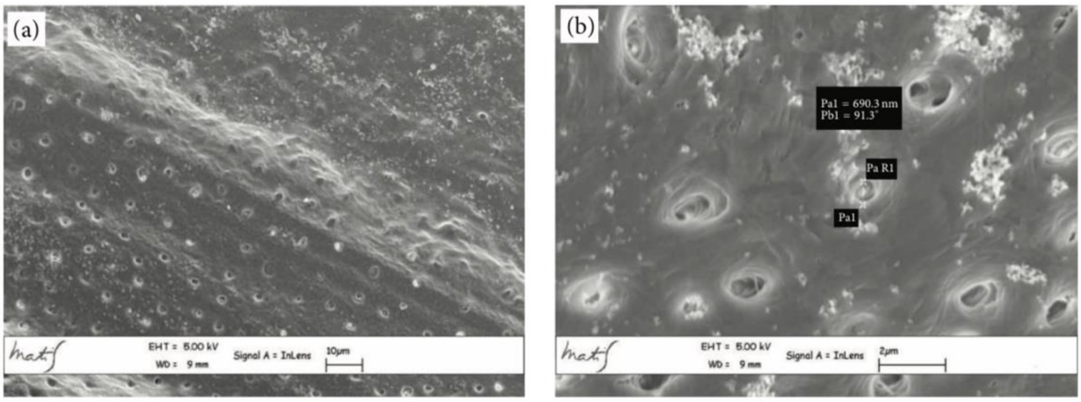

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Figure 5. The apical area metalized dentin specimens were examined using the Gemini Field Emission Scanning Electron Microscope (FEM-SEM) at a resolution of 1.7 μm and a pixel resolution of 3072 × 2304, with a magnification of 2500x. (A) 23000x (B) magnification [14].

2.2. Sealer

The precise application of root canal sealer is crucial for efficiently sealing the space between dentinal wall and the interface of the obturating core. Sealer are used to address voids and irregularities in root canal space, including lateral and accessory, as well as the spaces between gutta-percha points applied during lateral compaction. In addition to the primary role of sealing, sealer also serve as lubricants in the obturation process [15].

Grossman outlined the properties of an ideal sealer including tackiness when mixed to provide good adhesion between sealer and canal wall when set, hermetic seal, radiopacity, and visualization on a radiographic image. Furthermore, the powder is characterized by tiny particle size facilitating homogeneous dispersion in a liquid medium with no observed reduction in size during setting. An ideal sealer has no discoloration or staining on the tooth structure, possesses bacteriostatic properties, does not promote bacterial proliferation, has a slow set, insoluble in tissue fluids, does not irritate the surrounding periradicular tissue, easy to remove for retreatment and soluble with solvent [15,16].

The biocompatibility and tolerability of sealer by periradicular tissues must be ensured. When initially mixed, sealer possesses hazardous properties which subsequently decrease significantly with settling. The resorbable sealer can be absorbed by tissues and tissue fluids, while the removal from the periradicular tissues cannot be reliably anticipated. The process of tissue healing and restoration is typically not significantly impacted by the majority of sealer, in the absence of harmful byproducts that may arise over a prolonged period. The proliferative potential of periradicular cell populations may be negatively impacted by the breakdown products of sealer, particularly when an apical lesion is present. Consequently, it is not recommended to routinely insert sealer in the periradicular tissues as a component of an obturation approach [15,16].

2.3. Classification of Root Canal Sealer

Various sealer according to the primary constituent or structure include [17]: 1. Zinc Oxide Eugenol Sealer, which are Rickert's sealer/Kerr's Pulp Canal Sealer (Kerr manufacturing Co.) and ProcoSol (Star dental, Conshohocken, PA). 2. Non-Eugenol Zinc Oxide Sealer, which are Nogenol (G-C America, Alsip, III, Japan) and Canals-N (Syowa Yakuhin, Japan). 3. Calcium Hydroxide Sealer, which are Vitapex (NEO Dental, Japan) and Sealapex (Kerr Manufacturing Co.). 4. Glass Ionomer Sealer, which are Ketac Endo (3M ESPE, Seefled, Germany) and Endion (VOCO, Germany). 5. Gutta Percha Sealer/Chloroform-based Sealer which are, Chloropercha (Moyco, Union Broach, York, PA) and Rosin chloroform. 6. Sealer Containing Formaldehyde which are, Endomethasone and Riebler's paste (Amubarut, Germany). 7. Polymers which are, Resin-based Sealer (AH Plus/Thermaseal Plus/Topseal (Caulk, Dentsply) and Silicon-based Sealer (Endofill (Dentsply, Latin America, Brazil)). 8. Polycarboxylate Cements - as sealer. 9. Cyanoacrylate Cements - as sealer. 10. Titanium oxide-based Sealer. 11. Pastes used as a sole filling material. 12. Calcium-silicate based sealer which are, MTA-Fillapex (Angelus) and ProRoot Endo sealer (Dentsply). 13. Experimental Sealer.

2.4. Nanotechnology

2.4.1. Mechanism of Action

The electrostatic attraction between negative and positive charges leads to the interaction between positively charged nanoparticles and the negatively charged surface of microorganisms. The effective adhesion of cationic nanoparticles to the cellular membrane leads to the destabilization of the cell wall structure. This disturbance culminates in an elevation in cell permeability, which enables the admission of more nanoparticles into the bacteria. Consequently, the higher concentration of nanoparticles inside the bacteria leads to the release of cellular contents. The interaction between these nucleotide polymers and mesosomes affects multiple cellular activities, including respiration, division, and DNA replication [7].

The measurement of metabolic processes mostly depends on the maintenance of metal ion homeostasis in microbial systems. Excessive amounts of metal nanoparticles have been discovered to cause irreparable damage, leading to stunted growth or death of microorganisms. This mechanism interferes with a vital function in the bacteria [7].

Nanoparticles enter the cell membrane of microorganisms, leading to the release of reactive oxygen species (ROS). The occurrence of oxidative stress initiates a protective reaction inside the cell, resulting in an attack on the microorganism. This attack leads to a decrease in respiration and ATP synthesis, which in turn disrupts the cell membrane. The production of ROS by metal oxide is enhanced by active redox cycling and the presence of pro-oxidant functional groups at the interface of nanoparticles [7].

Nanoparticles stimulate the production of carbonyls, which have the ability to bind proteins. This phenomenon arises from the catalytic facilitation of the oxidative process inside amino acid sequences, resulting in the degradation of proteins, the inactivation of various enzymes, and the disturbance of catalytic efficiency [7].

The interaction between nanoparticles and nucleic acid molecules is known to influence the replication of chromosomal and plasmid DNA. The primary cause of this interaction can be traced to the electrical characteristics of nanoparticles, leading to the inhibition of signal transmission [7].

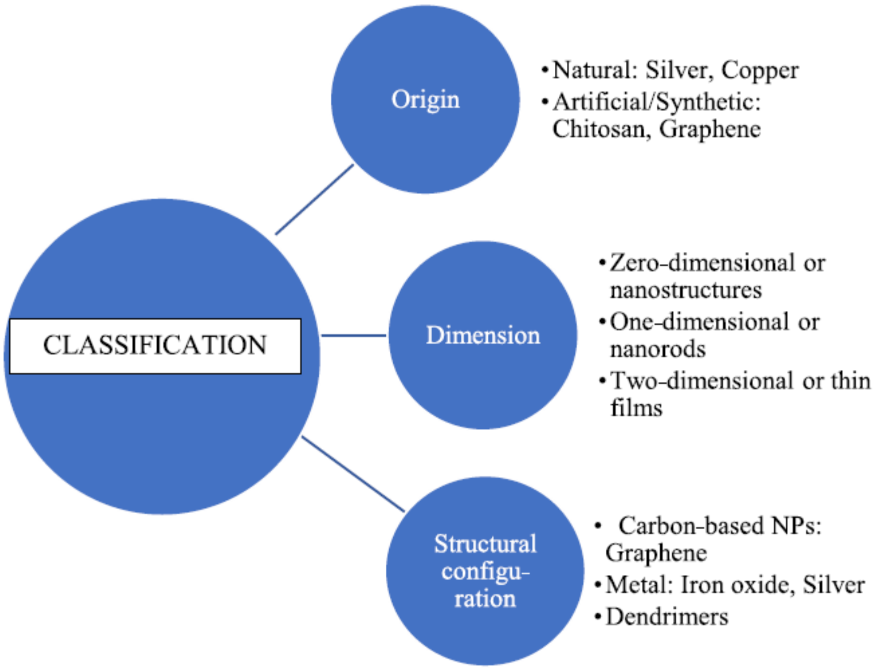

Figure 7. Classification of Nanoparticles [7].

2.5. Various Nanoparticles Used in Endodontics

2.5.1. Organic nanoparticles

Graphene, a carbon allotrope, can be identified by the extremely thin structure and the creation of a remarkably uniform crystal lattice without any structural defects. This specific nanoparticle is strategically utilized in illness diagnostics and detection, as well as in the creation of antibacterial surfaces. By incorporating graphene into silver nanoparticles, the ability to kill germs was maintained, while also reducing harmful effects on bones and soft tissues [7].

Chitosan is a chemically altered form of chitin, which is the second most abundant biopolymer found in nature. In general, it has exceptional antibacterial, antifungal, and antiviral characteristics. The activity of chitosan nanoparticles is based on the principle of electrostatic contact, which leads to the disruption of the cell membrane. Consequently, there is an increase in the permeability of the cell wall, resulting in cell death and the subsequent release of intracellular components [4,7,17].

The use of nanoparticles containing photoactive medicines is a crucial component in the elimination of germs from endodontic canals. The application of methylene blue-loaded nanoparticles in conjunction with light is used to decrease the microbial populations attached to root dentin and canal. The use of these particular nanoparticles holds significant importance in the field of endodontics [7].

2.5.2. Non-organic nanoparticles

Silicon dioxide (SiO_2), sodium oxide (Na_2O), and phosphorus pentoxide (P_2O_5) are the primary constituents of bioactive glass-based nanoparticles when present at modified concentrations. The size of the particles varies between 20 and 60 nanometers [7].

Mesoporous calcium silicate nanoparticles have a size distribution that extends from 80 to 100 nm, and possess a specific surface area with pore volume ratio. These nanoparticles are used to fill the apical third of root canals, due to the highly viscous nature [7].

Nanoparticle	Mechanical property	Physical property	Chemical property	Biological property
Graphene	1. highly stable 2. transparent 3. flexible material 4. increased ductility and malleability	1. High surface area is due to its peculiar structure. 2. Excellent electronic properties 3. Excellent optical properties.	1. Presence of a 2D structure comprising of single, thick carbon sheets arranged in a honeycomb pattern.	1. Good antimicrobial properties especially against S.mutans 2. Enhanced tissue dissolving properties. 3. Low toxicity level
Carbon nanotubes	1. Higher tensile strength as they have a hexagonal arrangement 2. Malleability is comparable to that of rubber 3. High ductility (8–12%) 4. Superior mechanical strength.	1. Large Surface area 2. Extremely light weight 3. Highly heat stable 4. Low density.	1. Good conduction efficiency 2. Superior bonding between these atoms making these NPs quite stable 3. Carbon atoms are arranged in the form of hexagonal rings	1. Enhanced antimicrobial properties 2. Ability to penetrate the bacterial cell membrane. 3. Induces inflammatory and fibrotic reactions under extreme conditions. 40 Potentially toxic in nature.
Silver nanoparticles	1. Good conductors of electricity 2. Possessing good malleability and ductility.	1. Due to its small size and high surface it confers excellent electrical, optical, thermal properties	1. Enhanced surface chemistry thereby making it an effective antibacterial agent	1. Effctive antimicrobial agent especially against E.faecalis. 2. Increased permeability in the bacterial cell membrane. 3. Highly biocompatible 4. Low toxicity levels.
Chitosan	1. Inactive and non-soluble in water alkali and organic solvents 2. pH more than 6	1. Soluble in various other mediums 2. Highly viscous, with a polyelectrolyte property.	1. It is a linear polyamine. 2. The presence of highly reactive hydroxyl and amino groups results in chelation of various transitional metal ions [38].	1. Excellent antibacterial, antifungal and antiviral properties. 2. Causes disruption of the bacterial cell membrane due to its electrostatic interaction.

Figure 8. Summarization of properties of commonly used nanoparticles in Endodontics [7].

2.5.3. Nanotechnology in Endodontics as Sealer/Nanosealer

The successful outcome of endodontic therapy is significantly dependent on the establishment of a hermetic seal through the process of root canal obturation. The application of sealer addresses deficiencies in the biomechanical preparation of root canals and enhances the adherence of the filling material to the walls of root canal [18]. Recent advancements in nanosealer, including nanocalcium hydroxide and nanobioactive glass, have demonstrated great potential to effectively inhibit the formation of biofilms at the interface between sealer and dentin. These nanosealers have shown promising results in enhancing sealing ability of dental materials while also reducing cytotoxic effects. The enhancement of the flow ability has several benefits in terms of improving the penetration of sealer into the microscopic dentinal tubules, leading to an enhanced ability to create seal [4,8,11].

3. Discussion

Despite extensive studies on enhancing the characteristics of gutta-percha, the requirement for sealer to achieve three-dimensional filling of canal system remains essential. Recent studies indicate that the use of sealer is of greater significance compared to other materials. The primary responsibility of an endodontic sealer is to ensure the impermeability of seal. The slight distortions and abnormalities that may arise between root canal wall and the stem filling material can be addressed through appropriate filling methods. Furthermore, sealer achieves microbiological control in case germs persist in the lateral canals or tubules [19,20].

Various sealers have weak antibacterial characteristics, with the observed outcome being dependent on the liberation of eugenol, paraformaldehyde, or zinc oxide. However, the aforementioned qualities gradually decrease as sealer passes through the setting process. The thickness of the endodontic sealer layer significantly impacts the quality of root canal filling. It is recommended to apply a thin and uniform layer to the walls of canal, as the material tends to shrink during the setting process, which might lead to the formation of undesirable voids. Previous studies also reported that sealer had a progressive dissolution process [19].

As stated by Bernardes et al, the flow of sealer is subject to the influence of filler particle size, with smaller particles resulting in increased sealer flow. The higher the volume of sealer flow, the greater the ability to effectively infiltrate uneven surfaces and access root canal based on ISO 6876:2012 (4,20). To enhance the adhesive properties of dental sealer and improve the ability to bond with the tooth dentin, the use of nanoparticles is implemented. This process enhances the integration of dental sealer with the underlying structural components of the tooth [11].

Satheesh et al. investigated the binding mechanism between chitosan nanoparticles and epoxy resin. The results showed that nanoparticles establish intermolecular connections with the epoxy component of the resin. Chitosan has polycationic properties due to amine groups (-NH2) and hydroxyl groups (-OH), which serve as reactive sites in creating more homogeneous mixtures. Therefore, chitosan can potentially serve as a filler substance in epoxy resins. Using nanofillers in epoxy-resin-based sealer leads to enhanced flow properties of sealer, facilitating improved adaptation to root canal wall [4].

Enggardipta et al. (2020) observed the dye penetration of gutta-percha and epoxy-resin-based sealer, with and without the addition of chitosan nanoparticles. The results showed that the samples with chitosan nanoparticles had the least amount of dye penetration. This suggests that the inclusion of chitosan nanoparticles in the epoxy-resin-based sealer enhances apical sealing ability, leading to a tighter and more effective seal [4]. Furthermore, Kishen et al. integrated chitosan and zinc oxide nanoparticles into an obturating sealer. Based on the results, the tested nanoparticles effectively prevented bacteria infiltration in canal. It was assumed that the inclusion into sealer yielded a favorable outcome. Zinc oxide nanoparticles have been synthesized for use as sealer. A commercially available product known as NanoSeal-S (Prevest DenPro) has been developed for this application. Del Carpio-Perochena et al. (2020) concluded that chitosan-loaded endodontic sealer demonstrated an extended duration of antibacterial effectiveness [7].

According to a study conducted by Wijaya G et al, the incorporation of 1% chitosan nanoparticles into the epoxy sealer group led to enhanced attachment to root canal. This result suggests an improved sealer penetration into root canal and a reduction in absorption [3]. Shetty et al. (2023) also found that the radiopacity of nanoparticle-based sealer was higher compared to epoxy-resin-based. This characteristic facilitates improved differentiation between obturating materials and the adjacent enamel and dentin [11].

Silver ions have been used to regulate bacteria proliferation in several medical contexts. However, the usage of silver as antibacterial agent experienced a downturn after the development of antimicrobial medicines. Antibacterial activity of silver ions is intricately connected to the interaction with thiol (sulfhydryl) groups. This interaction exerts a lethal impact on bacteria enzymes, growth, and cell division, ultimately leading to the impairment of cell walls and the contents. The recent increase of antibiotic-resistant species has led to a renewed interest in using silver as antibacterial agent. The efficacy of these silver particles is significantly enhanced when administered in nano-sized particles [5,6].

Hemmanur et al. (2020) conducted a study to evaluate the antimicrobial efficacy of zinc oxide and silver nanoparticles inserted into zinc oxide eugenol-based sealer. The results showed that silver nanoparticles had a more pronounced antibacterial impact compared to zinc oxide. The inclusion of zirconium oxide in mineral trioxide aggregate (MTA) led to enhanced strength and radiopacity while showing modest antibacterial activity against E. faecalis [5,6].

He et al. investigated antibacterial effectiveness of Graphene oxide nanoparticles (NPs) against prevalent infections such as *S. mutans*. It was concluded that these nanoparticles had a high level of efficacy in inhibiting growth. A study conducted by Rago et al., observed that graphene nanoplatelet, a derivative of graphene, showed antibacterial capabilities against a range of microbes, particularly *S. mutans*. SEM images demonstrated the presence of a robust mechanical bond between graphene nanoplatelet and cells. The bond entails the process of cell shrinkage and entrapment, finally resulting in the death of these microorganisms [7].

4. Conclusion

In conclusion, nanotechnology in dentistry was a huge part of a brighter future, particularly in the development of sealer. Due to the numerous benefits associated with these nanoparticles as sealing agent, the usage was highly advantageous. Current studies found that nanoparticles are more efficient and enhance the ability of sealer compared to without using any nanoparticles.

5. Acknowledgments

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6. Conflict of Interests

The authors declare no conflict of interest.

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