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Modification of Gutta-Percha in Endodontics: Surface Treatments and Nanoparticle Enhancements – An Evidence-Based Review

Manobharathi G[1], Sandhya Raghu[2]
[1]Post graduate student, Department of Conservative Dentistry and Endodontics, Saveetha Dental college and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077
[2]Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental college and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077
* Corresponding author
Sandhya Raghu, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-600077

Abstract

Endodontic treatment relies on effective cleaning, shaping, and obturation of the root canal system to eliminate microbial contamination and prevent reinfection. Gutta-percha (GP) remains the gold-standard core material due to its biocompatibility, dimensional stability, and long history of successful clinical use. However, GP lacks inherent antibacterial properties and adhesion to dentin, increasing the risk of persistent infection and treatment failure. Recent research has focused on enhancing GP through surface modifications, incorporation of antimicrobial agents, and nanotechnology-based approaches to improve its sealing ability, mechanical properties, and antibacterial efficacy. This review discusses the chemical composition, physical characteristics, and thermomechanical behavior of GP, followed by a comprehensive analysis of surface-modified and nanoparticle-enriched GP, including silver, nanodiamond, zinc oxide, titanium dioxide, gold, silica, calcium hydroxide, copper, and selenium nanoparticles. Findings from existing studies highlight significant improvements in antimicrobial activity, bonding strength, and sealing performance, suggesting that advanced GP formulations hold strong potential for reducing reinfection rates and improving long-term endodontic treatment outcomes. Further clinical studies are warranted to validate these promising results and establish standardized protocols for their use.

Keywords: Gutta Percha, Obturation, Nanoparticles, Modified Gutta Percha

INTRODUCTION

Endodontic treatment addresses the infected pulp of a tooth, aiming at the resolution of the infection and the prevention of reinfection. After the removal of the infected pulp tissue, the root canal space is cleaned, shaped and filled with a core root filling material. The success of endodontic treatment depends on thorough biomechanical preparation and irrigation of the root canal system[1]. With root filling, the goal is to maintain the aseptic chain obtained during the previous phases of root canal treatment[2]. This allows the canal space to be properly shaped and filled with an inert material, thereby preventing or minimizing the risk of reinfection. One of the leading causes of endodontic failure is the persistence of microbial infection. The critical role of bacteria in periradicular infections is well-documented, and the likelihood of treatment failure increases if microorganisms remain in the canal at the time of obturation[3]. Bacteria residing in complex root canal areas such as isthmuses, dentinal tubules, and lateral canals may evade standard disinfection methods. A study by Lin et al. involving 236 cases of failed endodontic treatments showed a clear association between the presence of bacterial infection and periradicular rarefaction.

Endodontic failure is often linked to persistent or secondary infections within the root canal system [4,5]. Among these, E.faecalis has been frequently identified as a particularly resilient intracanal pathogen commonly associated with endodontic treatment failures [6,7]. Gutta-percha (GP) cones are the most widely used core materials for root canal fillings due to their biocompatibility, affordability, long history of clinical use, and potential antimicrobial properties, largely attributed to their zinc oxide (ZnO) content. ZnO exhibits notable antimicrobial effects through interactions with bacterial surfaces and internal structures via different mechanisms [8]. Despite being manufactured under aseptic conditions, several studies have detected microbial contamination in freshly opened GP cone packages, with contamination risks increasing due to improper storage, exposure to aerosols, and handling. Staphylococcus species are among the most frequently isolated microorganisms from improperly handled GP cones.

To address contamination, immersing GP cones in various disinfectants is a common practice, providing both decontamination and added antimicrobial activity. Sodium hypochlorite (NaOCl) is often chosen for this purpose because of its low cost and broad-spectrum antimicrobial effectiveness. However, NaOCl can negatively impact the physical properties of GP cones, including their elasticity, tensile strength, and elongation, which may affect the quality of the root canal filling [9]. As a result, several physicochemical strategies have been explored to enhance the antimicrobial performance of GP cones while preserving their essential mechanical properties. These include incorporating antimicrobial agents like chlorhexidine, calcium hydroxide, or bioactive phosphate glasses, as well as using nanotechnology-based methods, such as developing nanodiamond-reinforced GP composites [9–11]; [12].

Obturation

Obturation is the process of completely filling the entire root canal system in three dimensions, using root canal sealers to create an effective seal. According to the American Association of Endodontics, root canal obturation is defined as the three-dimensional filling of the entire root canal system as close to the cementodentinal junction as possible [13]. An inadequate root filling is one of the factors contributing to treatment failure. Research has shown that bacteria play a significant role in the failure of endodontic treatment. Achieving successful treatment involves not only thorough cleaning and shaping of the root canal system but also its proper three-dimensional obturation, which prevents microorganisms from re-entering the canal and stops tissue fluids from percolating back into the system [14].

Objectives of obturation

Proper obturation is essential for the success of root canal treatment, as it ensures a complete seal of the root canal system, preventing reinfection by bacteria or other microorganisms. It eliminates pathogens, prevents leakage, and promotes healing of the surrounding tissues. By maintaining the tooth's structural integrity and minimizing the risk of post-treatment complications, proper obturation significantly enhances the long-term success of the procedure and contributes to the overall comfort and recovery of the patient [15].

The primary objectives of obturation in root canal treatment are as follows:

Sealing the Root Canal System: The primary objective of obturation is to provide a complete, three-dimensional seal of the root canal system. This helps prevent the ingress of bacteria, fluids, and other contaminants into the canal, which could lead to reinfection.

Prevention of Microbial Re-infection: By sealing the canal effectively, obturation helps to eliminate the presence of microorganisms and prevents new ones from entering, thereby reducing the risk of post-treatment infections.

Isolation of Periapical Tissues: Proper obturation prevents periapical tissues from being exposed to harmful substances, such as bacteria or inflammatory mediators, which may cause persistent periapical disease or further damage to the surrounding tissues.

Stabilizing the Root Canal Structure: Obturation helps to maintain the integrity of the treated tooth, providing structural support to prevent fractures or collapse of the tooth after endodontic therapy.

Promoting Healing of Periradicular Tissues: A well-sealed root canal system allows for the healing of periapical tissues by preventing the re-entry of bacteria and tissue fluids, thereby promoting the resolution of apical periodontitis and encouraging the restoration of health to the surrounding tissues.

Prevention of Microleakage: An adequately placed obturation material minimizes the risk of microleakage, which can occur over time if the sealing material is not well adapted to the root canal walls, leading to reinfection and treatment failure.

Long-Term Treatment Success: Effective obturation, when combined with proper cleaning and shaping, is essential for the long-term success of endodontic therapy. It ensures that the root canal remains free of bacterial contamination, thus enhancing the overall prognosis of the treated tooth.

Obturating materials

Gutta percha

Gutta-percha (GP) is a biocompatible, thermoplastic material that has been the gold standard for root canal obturation in endodontics for over a century. Root canal obturation is a crucial step in endodontic therapy, aimed at filling the empty root canal space after cleaning and shaping. The goal is to prevent bacterial reinfection, block the ingress of fluids, and provide a stable, long-term seal to preserve the health of the tooth and surrounding tissues. Gutta-percha is highly valued for its unique properties, including its ability to adapt to the root canal system, ease of use, and excellent sealing characteristics.

Originally derived from the latex of the Palaquium tree, gutta-percha is composed primarily of polyisoprene, a polymer that gives it its characteristic physical properties. Despite the advent of alternative materials, gutta-percha remains widely used due to its predictable performance, favorable biocompatibility, and adaptability to the complex anatomy of the root canal system. It is radiopaque, allowing for easy visualization during radiographic examinations, and is stable over time, ensuring long-term success in endodontic treatments[8].

Chemistry

Natural rubber and gutta-percha are both composed of polyisoprene, but they differ significantly in their polymer configurations—natural rubber features the cis-form, while gutta-percha is in the trans-form. This difference leads to distinct molecular structures: natural rubber's cis-configuration places CH_2 groups on the same side of the double bond, resulting in coiled, flexible chains that contribute to its high elasticity and flexibility. In contrast, gutta-percha's trans-configuration arranges CH_2 groups on opposite sides of the double bond, forming straighter, more rigid chains that encourage crystallization, making the material harder and more brittle. These molecular differences influence their physical properties and processing behaviors: natural rubber is elastomeric, highly deformable, and easy to manipulate, though sensitive to temperature changes, while gutta-percha, being more rigid and less elastic, offers better dimensional stability under various conditions but is harder to process[8,16].

Physical and Thermomechanical properties of gutta percha

Gutta-percha (GP) is a thermoplastic and viscoelastic material that is sensitive to temperature changes. At room temperature, it is solid and stiff but becomes soft at 60°C and melts around 95°C–100°C, with partial degradation occurring at higher temperatures. Prolonged exposure to light and air can cause GP to become brittle due to oxidation. Its physical properties, such as tensile strength, stiffness, brittleness, and radiopacity, are influenced by both its organic components (GP polymer and wax/resins) and inorganic elements like zinc oxide and metal sulfates. Zinc oxide, for example, increases brittleness and reduces elongation and tensile strength[17]. The viscoelasticity of GP is crucial during the obturation process, allowing the material to deform under continuous load and flow for effective condensation. The transformation temperatures for GP range from 48.6°C–55.7°C for the β-to-α-phase transition and 59.9°C–62.3°C for the α-to-amorphous transition. Heating beyond 130°C can lead to degradation. Over the years, various additives have been incorporated to enhance GP's properties and improve its clinical performance[18].

Modifications of Gutta Percha

Surface Modified Gutta Percha

One of the limitations of traditional gutta percha (GP) is its lack of true adhesion to the root canal walls. To overcome this, surface modification techniques have been developed to enhance its adaptability and bonding capacity with various materials. Some of these modifications include:

Resin Coated Gutta Percha: A resin is created by combining diisocyanate with hydroxyl-terminated polybutadiene, which is then grafted with a hydrophilic methacrylate group. This modification improves GP's ability to bond with methacrylate-based resin sealers, increasing its adhesion properties [19]

Glass Ionomer Coated Gutta Percha: The glass ionomer coating creates a true monoblock obturation by forming an ionic bond with the dentin. This modification is non-resorbable and remains unaffected by residual sodium hypochlorite, contributing to a stronger seal[20,21].

Bioceramic Coated Gutta Percha: Incorporating bioceramic materials, typically in nanoparticle form, enhances GP's sealing ability by taking advantage of the natural moisture in dentin. These bioceramics promote slight expansion, improving the seal and preventing shrinkage, which is beneficial for achieving a more effective obturation [22]

Nonthermal Plasma Coated Gutta Percha: Treatment with argon and oxygen plasma increases the wettability of GP, promoting better adhesion to the sealer. Argon plasma modifies the chemical structure of GP, while oxygen plasma enhances surface roughness, facilitating stronger bonding.

Medicated Gutta Percha: Medicated gutta percha is infused with antimicrobial agents to provide additional therapeutic benefits during root canal therapy. Commonly used medicated GP formulations include:

Iodoform-Impregnated Gutta Percha: Containing 10% iodoform, this variant has antimicrobial effects against bacteria such as Staphylococcus aureus and Streptococcus sanguis. However, it is less effective against Enterococcus faecalis and Pseudomonas aeruginosa [23].

Calcium Hydroxide Gutta Percha: Combining the antimicrobial benefits of calcium hydroxide with the bio-inertness of GP, this formulation acts as an intracanal medicament, raising the pH in the canal to inhibit microbial growth[24].

Chlorhexidine-Impregnated Gutta Percha: Chlorhexidine, a broad-spectrum antimicrobial agent, is incorporated into GP to provide enhanced effectiveness against Enterococcus faecalis and Candida albicans[24,25].

Tetracycline-Infused Gutta Percha: Containing tetracycline, this variant is effective against a wide range of bacteria, including Staphylococcus aureus, with reduced activity against Enterococcus faecalis [26].

Cetylpyridinium Chloride (CPC)-Impregnated Gutta Percha: Though not commercially available, this version contains CPC, a quaternary ammonium compound with antimicrobial properties. It disrupts microbial membranes and enhances the antimicrobial effect of GP [27].

Nanoparticles-Enriched Gutta Percha: The use of nanotechnology has advanced the development of gutta percha, particularly in enhancing its antimicrobial properties and improving treatment outcomes. Some notable nanoparticle-enhanced formulations include:

Nanodiamond-Embedded Gutta Percha: Nanodiamonds (NDs) are incorporated into GP along with amoxicillin to create a composite with improved mechanical properties and antimicrobial activity. This formulation enhances the success rate of root canal treatments by reducing the likelihood of reinfection [10,27].

Silver Nanoparticle-Coated Gutta Percha: The addition of silver nanoparticles to GP improves its antibacterial properties. Silver ions exhibit sustained ion release and long-term antimicrobial activity, effective against bacteria like Enterococcus faecalis, Staphylococcus aureus, and Candida albicans. This modification enhances the antibacterial efficacy of GP, reducing the risk of post-treatment infection[28].

These advanced modifications of gutta percha aim to enhance its effectiveness in endodontic treatment, improving both the sealing properties and antimicrobial performance, thereby reducing the risk of treatment failure and promoting better long-term outcomes.

Nanomaterials in modification of Gutta Percha

Nanotechnology has revolutionized the development of materials in endodontics, particularly in the modification of gutta-percha (GP) for improved antibacterial properties, sealing ability, and overall performance. The incorporation of nanoparticles into GP has been explored to enhance the physical, chemical, and biological properties, as well as to address issues like infection control, biocompatibility, and dimensional stability. Here is a summary of various nanoparticles used to modify gutta-percha based on recent studies and reviews

Silver Nanoparticles (AgNPs)

Silver nanoparticles are widely used due to their well-documented antimicrobial properties. They release silver ions that exhibit broad-spectrum antibacterial effects, particularly against Enterococcus faecalis, Staphylococcus aureus, Candida albicans, and Escherichia coli. Silver nanoparticles have also been incorporated into gutta-percha to enhance its antimicrobial efficacy and promote long-term antibacterial activity[29]. Studies have demonstrated that silver nanoparticle-coated GP shows reduced bacterial growth and better overall performance in preventing reinfection within the root canal system.

Nanodiamonds

Nanodiamonds (NDs) are carbon-based nanoparticles that have shown promise in improving the mechanical properties and antimicrobial efficacy of GP. Their high surface area, biocompatibility, and ability to adsorb antibiotics (e.g., amoxicillin) make them ideal for inclusion in endodontic sealers. ND-modified gutta-percha has shown better sealing ability and enhanced mechanical strength, making it more resistant to extrusion and more effective at sealing the root canal [10,30].

Zinc Oxide Nanoparticles (ZnO NPs)

Zinc oxide nanoparticles have been added to gutta-percha to enhance its antibacterial properties and bioactivity. Zinc oxide possesses inherent antimicrobial properties and has been shown to enhance the sealing capacity of gutta-percha. Additionally, ZnO nanoparticles can stimulate the regeneration of periapical tissues by promoting osteoblast activity. The addition of ZnO nanoparticles to GP has also been reported to improve the material's dimensional stability and resistance to extrusion [10,30,31].

Titanium Dioxide Nanoparticles (TiO2 NPs)

Titanium dioxide nanoparticles are incorporated into GP to improve its antimicrobial properties and biocompatibility. TiO2 NPs are known for their photocatalytic properties, which can enhance the disinfection process when exposed to light. Additionally, TiO2 NPs improve the mechanical properties of GP and reduce the risk of microbial colonization in root canal treatments [32].

Gold Nanoparticles (AuNPs)

Gold nanoparticles have been incorporated into gutta-percha to enhance its antibacterial properties. Gold NPs possess unique properties such as surface plasmon resonance, which contribute to their antimicrobial efficacy. The incorporation of AuNPs into GP has been shown to provide long-lasting antibacterial effects, which are beneficial for preventing bacterial re-entry into the root canal system [33].

Silica Nanoparticles (SiO_2 NPs)

Silica nanoparticles are used to enhance the surface properties of gutta-percha, particularly its wettability and adhesion to dentin. SiO_2 nanoparticles improve the flowability of GP, ensuring better adaptation to the root canal walls. Moreover, they have been found to enhance the mechanical properties of GP, making it more resistant to fracture and improving its overall sealing ability[34].

Calcium Hydroxide Nanoparticles ($Ca(OH)_2$ NPs)

Calcium hydroxide nanoparticles have been added to gutta-percha to combine the antimicrobial and tissue-regenerative properties of calcium hydroxide with the sealing ability of GP. This modification is particularly useful in cases where antimicrobial effects and healing of periapical tissues are crucial. Calcium hydroxide nanoparticles release hydroxyl ions, which have a high pH that helps eliminate bacteria within the root canal system[29,35].

Copper Nanoparticles (Cu NPs)

Copper nanoparticles have been explored for incorporation into GP to leverage their potent antimicrobial properties. Copper nanoparticles exhibit significant antibacterial effects against a broad spectrum of pathogens, including multidrug-resistant strains. The addition of Cu NPs to GP helps in maintaining a sterile environment within the root canal system, reducing the chances of infection recurrence[36].

Selenium nanoparticles

Selenium is an essential micronutrient in biological systems[37]. Due to its antimicrobial, anticancer, antioxidant effects, SeNPs have many nanomedicine applications, and their cytotoxicity is lower than most commonly used silver nanoparticles. Selenium nanoparticles (SeNPs) have been utilized in various biomedical applications, yet their antimicrobial potential in endodontics remains largely unexplored. Among the different chemical synthesis methods, SeNPs are typically produced by reducing selenite or selenous acid using agents such as glutathione (GSH), hydrazine, sodium borohydride ($NaBH_4$), stannous chloride ($SnCl_2$), L-cysteine, ascorbic acid, sodium thiosulfate ($Na_2S_2O_3$), and sodium dodecyl sulfate (SDS)[38].

The antibacterial action of these NPs is due to their ability to produce reactive oxygen species (ROS), depleting internal ATP, and disrupting membrane potential which leads to bacterial cell death [36]. Due to their low toxicity and anticancer properties, their therapeutic benefits have been proven in many disorders like arthritis, nephropathy, diabetes, and cancer[39]. Nanotoxicology has been a major concern since the advent of biomedical applications of Nanoparticles. Selenium Nanoparticles have 4-6 times lower toxicity as compared to selenium oxyanions, such as SeO_3 −2 and SeO_4 −2 [36].

Severe toxicity due to SeNPs occurs only at higher doses. The median lethal dose (LD50) is 92.1 mg Se/kg for Nano-Se which is much higher than what was used in existing studies[20]. Since the cytotoxicity of SeNPs is lower than most used silver nanoparticles, they offer promising potential in the field of endodontics, though the results need to be clinically extrapolated.

Analysis of Existing Studies on Surface-Modified Gutta Percha

Overview of Relevant research

Various modifications of gutta-percha (GP) have been explored to enhance its clinical performance in root canal obturation. Medicated GP, which incorporates antimicrobial agents like calcium hydroxide, iodoform, and chlorhexidine, is designed to improve antibacterial properties and reduce the risk of reinfection. Nanoparticle-coated GP, such as those with silver or titanium dioxide nanoparticles, has been investigated for its enhanced antibacterial action, improved mechanical properties, and increased surface wettability, which facilitates better adhesion to dentin and sealing ability. Resin-incorporated GP, on the other hand, addresses the poor bonding between GP and dentin by improving adhesion and enhancing the material's sealing capacity.

The methodologies used to assess these modified GP materials include antimicrobial testing, such as agar diffusion tests and zone of inhibition assays, to evaluate their ability to inhibit bacterial growth. Additionally, bond strength testing (push-out or microtensile tests) is commonly employed to measure the adhesion of GP to dentin, with improved bonding leading to better sealing and fewer micro leakages. Sealing ability is often assessed using fluid filtration or dye leakage tests. The mechanical properties, including tensile strength, compressive strength, and dimensional stability, are tested to ensure the modified GP materials maintain the necessary physical properties for clinical success. Other assessments, such as radiopacity evaluation and cytotoxicity tests, are performed to ensure that the modified materials are safe for clinical use. These studies have demonstrated that modified GP formulations generally offer improved antimicrobial effects, sealing ability, and mechanical properties, contributing to better long-term outcomes in endodontic treatments [27].

Findings and Outcomes of existing studies

Tomino et al. (2016) investigated the antimicrobial activity of GP supplemented with CPC at concentrations of 0.05%, 0.2%, and 0.8%. The study found that adding CPC significantly increased the antimicrobial efficacy of GP against eight representative endodontic pathogens, including both gram-positive and gram-negative bacteria, as well as fungi. The addition of 0.05%, 0.2%, and 0.8% CPC reduced the viable microbial count to below the detection limit (20 CFU/mL) for all tested pathogens, except Pseudomonas aeruginosa, which was detected in the 0.8% CPC-containing GP but at a significantly reduced level. These results suggest that CPC-modified GP could be effective in preventing microbial infections during root canal therapy[27]. Melker et al. (2006) evaluated the antimicrobial efficacy of iodoform-containing GP against Actinomyces israelii, Actinomyces naeslundii, Enterococcus faecalis, and Fusobacterium nucleatum using the agar diffusion method. The study found that standard GP and iodoform-containing GP inhibited F. nucleatum and A. naeslundii, with iodoform-containing GP also inhibiting A. israelii. Tetracycline-containing GP inhibited growth from all four bacterial species tested. These findings suggest that iodoform-modified GP may serve as a useful complement to the cleaning and disinfection phase of root canal procedures [40].

Lee et al. (2015) developed a nanodiamond (ND)-embedded GP functionalized with amoxicillin. The study demonstrated that ND-embedded GP exhibited improved mechanical properties compared to unmodified GP. Additionally, ND-embedded GP functionalized with amoxicillin effectively inhibited bacterial growth, suggesting its potential as a novel endodontic therapy platform for improved treatment outcomes [10]. The systematic review also highlighted studies incorporating chlorhexidine into GP, which significantly enhanced its antimicrobial efficacy, particularly against Enterococcus faecalis. This combination was effective in reducing bacterial counts within the root canal system [10,32][32].

Embedding silver nanoparticles into GP resulted in increased antibacterial activity, attributed to the nanoparticles' broad-spectrum antimicrobial properties. Coating GP with nanocurcumin significantly improved its antibacterial activity against Escherichia coli. Nanocurcumin-coated GP exhibited a more uniform and tightly adherent surface compared to curcumin-coated GP, resulting in enhanced antimicrobial properties [41]. Tetracycline-containing GP demonstrated broad-spectrum antimicrobial activity, inhibiting growth from all tested bacterial species. This suggests that incorporating tetracycline into GP could enhance its effectiveness as a root canal filling material.

CONCLUSION

Gutta-percha continues to be the standard obturation material in endodontics; however, its lack of intrinsic adhesion and limited antimicrobial activity have spurred the development of advanced modifications. Surface treatments and nanotechnology-based enhancements have shown potential to improve sealing ability, durability, and biological performance, thereby reducing microleakage and reinfection rates.

REFERENCES

1. Arun N, Solete P, Jeevanandan G, Antony DP, Sairaman S, S S. Comparative Evaluation of the Removal of Gutta Percha From the Root Canal Using Various Retreatment File Systems With and Without Magnification: An In Vitro Study. Cureus. 2024 Jun;16(6):e62128.
2. Sairaman S, Solete P, Jeevanandan G, Antony SDP, Kavoor S, Sandeep AH. Comparative evaluation of the remaining dentin thickness using Solite RS3 and ProTaper Universal retreatment files: A nanocomputed tomography study. Endodontology. 2024 Apr;36(2):175–80.
3. Shah T, Ramesh S, Sugumaran S, Choudhari S. Endodontic retreatment efficacy with and without solvents: A systematic review. J Conserv Dent Endod. 2023 Nov 22;26(6):610–5.
4. Tabassum S, Khan FR. Failure of endodontic treatment: The usual suspects. Eur J Dent. 2016 Jan-Mar;10(1):144-7.
5. Nishitha Arun, Pradeep Solete, Ganesh Jeevanandan, Delphine Priscilla Antony S, Sowmya Kavoor, & Adimulapu Hima Sandeep. View of Comparison of time required by three different retreatment file systems for retrieval of Gutta Percha- An In Vitro Study [Internet]. [cited 2025 Sep 1]. Available from: https://doi.org/10.47750/jptcp.2023.30.10.044
6. Tabassum S, Khan FR. Failure of endodontic treatment: The usual suspects. Eur J Dent. 2016 Jan-Mar;10(1):144–7.
7. Alghamdi F, Shakir M. The Influence of Enterococcus faecalis as a Dental Root Canal Pathogen on Endodontic Treatment: A Systematic Review. Cureus. 2020 Mar 13;12(3):e7257.
8. Vishwanath V, Rao HM. Gutta-percha in endodontics - A comprehensive review of material science. J Conserv Dent. 2019 May-Jun;22(3):216–22.
9. Tilakchand M, Naik B, Shetty AS. A comparative evaluation of the effect of 5.25% sodium hypochlorite and 2% chlorhexidine on the surface texture of Gutta-percha and resilon cones using atomic force microscope. J Conserv Dent. 2014

Jan;17(1):18–21.
10. Lee DK, Kim SV, Limansubroto AN, Yen A, Soundia A, Wang CY, et al. Nanodiamond-Gutta Percha Composite Biomaterials for Root Canal Therapy. ACS Nano. 2015 Nov 24;9(11):11490–501.
11. Chandran N, Ramesh S, Shanmugam R. Synthesis of Silver Nanoparticles Using Azadirachta indica and Syzygium aromaticum Extract and Its Antibacterial Action Against Enterococcus faecalis: An In Vitro Study. Cureus. 2024 Jul;16(7):e65044.
12. Carvalho CN, Martinelli JR, Bauer J, Haapasalo M, Shen Y, Bradaschia-Correa V, et al. Micropush-out dentine bond strength of a new gutta-percha and niobium phosphate glass composite. Int Endod J. 2015 May;48(5):451–9.
13. Schilder H. Filling root canals in three dimensions. 1967. J Endod. 2006 Apr;32(4):281–90.
14. Kapoor K. Endodontic obturation techniques. Int J of Health Sci. 2024 Aug 9;8(S1):1033–40.
15. Tomson RME, Polycarpou N, Tomson PL. Contemporary obturation of the root canal system. Br Dent J. 2014 Mar;216(6):315–22.
16. Goodman A, Schilder H, Aldrich W. The thermomechanical properties of gutta-percha: II. The history and molecular chemistry of gutta-percha. Oral Surgery, Oral Medicine, Oral Pathology. 1974 Jun 1;37(6):954–61.
17. Pai-Chun Huang, Yi-Ting Wu, Yung-Hao Hsu, Szu-Chin Liao, Ya-Hsuan Wang, James L. Gutmann, Haw-Ming Huang, Sung-Chih Hsieh. Composition and physical properties of gutta-percha endodontic filling materials. Journal of Endodontics. 1977 Aug 1;3(8):304–8.
18. Combe EC, Cohen BD, Cummings K. Alpha- and beta-forms of gutta-percha in products for root canal filling. International Endodontic Journal. 2001 Sep 1;34(6):447–51.
19. Tay FR, Loushine RJ, Monticelli F, Weller RN, Breschi L, Ferrari M, et al. Effectiveness of resin-coated gutta-percha cones and a dual-cured, hydrophilic methacrylate resin-based sealer in obturating root canals. J Endod. 2005 Sep;31(9):659–64.
20. Website [Internet]. Available from: https://doi.org/10.9734/jpri/2020/v32i2730853
21. Khanvilkar U, Dundappa J, Chaubey N, Jha A, Paliwal A, Kumar R. Comparison of Apical Sealing Capacity of ActiV GP/Glass Ionomer Sealer Versus Resilon/RealSeal and Gutta Percha/AH plus Sealers. Cureus. 2023 Dec;15(12):e49931.
22. Prado M, Menezes MS de O, Gomes BPF de A, Barbosa CA de M, Athias L, Simão RA. Surface modification of gutta-percha cones by non-thermal plasma. Mater Sci Eng C Mater Biol Appl. 2016 Nov 1;68:343–9.
23. Shur AL, Sedgley CM, Fenno JC. The antimicrobial efficacy of “MGP” gutta-percha in vitro. Int Endod J. 2003 Sep;36(9):616–21.
24. Website [Internet]. Available from: https://doi.org/10.3390/app14010388
25. Lui JN, Sae-Lim V, Song KP, Chen NN. In vitro antimicrobial effect of chlorhexidine-impregnated gutta percha points on Enterococcus faecalis. International Endodontic Journal. 2004 Feb 1;37(2):105–13.
26. Bodrumlu E, Alaçam T, Semiz M. The antimicrobial and antifungal efficacy of tetracycline-integrated gutta-percha. Indian J Dent Res. 2008 Apr-Jun;19(2):112–5.
27. Tomino M, Nagano K, Hayashi T, Kuroki K, Kawai T. Antimicrobial efficacy of gutta-percha supplemented with cetylpyridinium chloride. J Oral Sci. 2016;58(2):277–82.
28. Shantiaee Y, Maziar F, Dianat O, Mahjour F. Comparing microleakage in root canals obturated with nanosilver coated gutta-percha to standard gutta-percha by two different methods. Iran Endod J. 2011 Nov 15;6(4):140–5.
29. A. Mohan, S. Dipallini, S. Lata, S. Mohanty, P.K. Pradhan, P. Patel, H. Makkar, S.K. Verma. Oxidative stress induced antimicrobial efficacy of chitosan and silver nanoparticles coated Gutta-percha for endodontic applications. Materials Today Chemistry. 2020 Sep 1;17:100299.
30. K. Monisha, S. Antinate Shilpa, G.S. Hikku. In-situ nano-Ag coated gutta percha cones to counteract internal endodontic failures through bacterial infections. Materials Chemistry and Physics. 2023 Jun 1;301:127532.
31. Alves MJ, Grenho L, Lopes C, Borges J, Vaz F, Vaz IP, Fernandes MH. Antibacterial effect and biocompatibility of a novel nanostructured ZnO-coated gutta-percha cone for improved endodontic treatment. Materials Science and Engineering: C. 2018 Nov 1;92:840–8.
32. Manobharathi G, Raghu S, Krishnan A. Antimicrobial efficacy of modified gutta-percha for obturation - A systematic review. J Conserv Dent Endod. 2025 Jan;28(1):2–9.
33. Mierzejewska ŻA, Rusztyn B, Łukaszuk K, Borys J, Borowska M, Antonowicz B. The Latest Advances in the Use of Nanoparticles in Endodontics. Applied Sciences. 2024 Sep 5;14(17):7912.
34. Afkhami F, Chen Y, Walsh LJ, Peters OA, Xu C. Application of Nanomaterials in Endodontics. BME Front. 2024 Apr 17;5:0043.
35. Website [Internet]. Available from: https://doi.org/10.1016/S0099-2399(99)80285-4
36. Website [Internet]. Available from: http://dx.doi.org/10.4067/S0718-381X2016000300024
37. Shanmugam R, Anandan J, Balasubramanian AK, Raja RD, Ranjeet S, Deenadayalan P. Green Synthesis of Selenium, Zinc Oxide, and Strontium Nanoparticles and Their Antioxidant Activity - A Comparative In Vitro Study. Cureus. 2023 Dec;15(12):e50861.
38. Sneka, Santhakumar P. Antibacterial Activity of Selenium Nanoparticles extracted from Capparis decidua against Escherichia coli and Lactobacillus Species. Res J Pharm Technol. 2021 Aug 6;4452–4.
39. A.Ruhina hussaini, S Rajeshkumar, & T Lakshmi. View of Antidiabetic activity of selenium nanoparticle synthesized using clove and cumin formulation [Internet]. [cited 2025 Aug 29]. Available from: https://doi.org/10.47750/jptcp.2023.30.13.013
40. Melker KB, Vertucci FJ, Rojas MF, Progulske-Fox A, Bélanger M. Antimicrobial efficacy of medicated root canal filling materials. J Endod. 2006 Feb;32(2):148–51.
41. Panwar D, Sidhu K, Bhushan J, Kakkar V, Mehta M, Sharma J. Evaluation of antimicrobial efficacy of nanocurcumin-coated gutta-percha against : An study. J Conserv Dent. 2023 Mar 16;26(2):160–4.