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REVIEW

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A Review on Fungal Nanoparticales as Antimicrobial Agents to Control Oral Biofilms

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Abstract

A variety of materials and drugs have been used in dental care to protect the oral cavity from microbial activities, particularly the formation of dental biofilms. These compounds have the potential to be harmful to the human body. Despite these challenges, nanotechnology applications in dentistry have been developed and used with some success in the improvement of restorative materials. It also focuses on several problematic parts of dental care, like oral biofilm communities, and also how nanotechnology may assist overcome these obstacles. Nanoparticles (NPs) are frequently used in the medical sector for a numerous application, and investigations have already shown that NPs have antimicrobial effects. The extensive utilization of silver nanoparticles (AgNPs) has raised their consumption. Nanotechnology has been used effectively in the development of restorative materials in dentistry. Traditional AgNPs production methods require the use of toxic chemicals and dangerous solvents. There is a need for novel approaches for synthesizing AgNPs that use environmentally friendly agents and fluids. It really is important to look for suitable production settings in order to validate a good AgNP synthesis. Green techniques are the most commonly used in this industry since they are both environmentally friendly and economically effective. Biological NPs generated from fungal secretions. Biological NPs synthesized from fungal secretions or extracts are used in safe synthesis because they outperform chemical procedures. The objective of this review paper is to understand the role of fungal AgNPs as antimicrobial agents in dentistry, mainly in the reduction of oral biofilm communities.

Keywords: Nanoparticles oral biofilm, Fungal nanoparticles, Silver nanoparticles

1. Introduction

Dental biofilms containing oral bacteria and fungi can give rise to a number of localized dental diseases, including tooth decay, gingival inflammation, periodontal diseases, candida infection, root canal system infections, and orthodontic infections. A broad range variety of organisms, such as bacteria and yeasts, can grow in the buccal mucosa. It is a structured community made up of a diverse range of microbes embedded in a self-organized matrix of extracellular polysaccharides (EPS), and it has been identified as a pathogenicity in several oral infectious diseases such as carious lesions, gum disease, periodontal diseases, periapical gingival inflammation, and peri-implantitis [3]. Controlling oral biofilm is expensive all over the world [4, 5]. Nanotechnology is a branch of science that deals with nanometer-sized objects known as nanoparticles (NPs). AgNPs are rapidly being used in a variety of disciplines, including medicine and health care, due to their distinct physical and chemical properties. These materials are made on a nanoscale and are safe to use in the human body [6, 7]. Nanoparticles are of great scientific interest because they serve as a link among both composite counterparts and atoms and molecules structures. They are currently the subject of intense scientific research due to their wide range of potential applications. NPs research is currently undergoing extensive scientific investigation due to the broad range of potential applications in biomedical domains [8]. Nanomedicine is a scientific discipline that combines nanotechnology with medications or diagnostic compounds to improve the ability to target specific

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cells or tissues. The diagnosis and treatment of a wide range of diseases are among the nanotechnology therapeutic applications. Furthermore, NPs and nanoproducts are increasingly being used in dentistry [9, 10]. Nanostructured titanium surfaces for implants that have an antibacterial effect without the use of antibiotics are one example of nanostructures that may be useful in dentistry [11]. Streptococcus mutants are an etiological agent in the development of dental caries and other periodontal disorders, and oral biofilms are crucial to the formation of carious lesions. The nanoparticles has a high potential for combating biofilms caused by S. mutans [12]. The unique properties of NPs provide opportunities for medical sciences, which motivates ongoing research in the field of nanomaterials [13, 14]. The purpose of this review is to discuss the use of silver AgNPs in dentistry, their generation or synthesis from fungal extracts or exudates, their antibacterial properties, and their effectiveness in controlling oral biofilms.

2. Methods

A large number of related papers and studies are consulted and summarized in this review.

3. Biotic production and applications of NPs

The biologically active synthesis of metal NPs includes the strategy is acceptable of metal salts to elemental metal, that can be maintained by biological compounds found in microbes including fungus and bacteria. In general, NPs have been synthesized in three main ways: physically, chemically, and biologically. Physical and chemical approaches are significantly more expensive, and they involve toxic, harmful compounds that may cause biotic and environmental issues [16]. Although biological methods are used to produce NPs, the increased demand for material synthesis that is both economically feasible and environmentally friendly has led to the search for a good production [17]. Fungi, bacteria, and plant extracts are three important biological sources of AgNPs. Bottom-up biosynthesis of AgNPs involves oxidation reduction processes, with reducing characteristics or microbial enzymes that generate the required NPs by acting on their respective components [18]. The biological process incorporates three critical ingredients in the production of NPs: environmentally friendly reducing agents, a manufacturing solvent medium, and nontoxic stabilizing agents [19]. AgNPs are important in the medical profession because of their distinct characteristics and use in daily life by humans. Other methods that are primed for AgNPs are extensively used in other fields [20, 21].

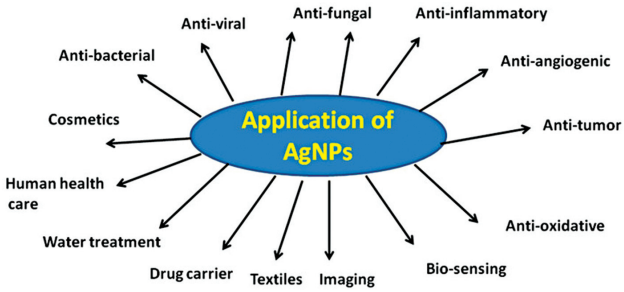

Fig. 1. Various applications of AgNPs in different fields.

When a large surface area is permitted by a small size of NPs, the influence of NPs is expanded. By use of nano-sized particles, that would provide the better health impact to iron features, raises the potential of silver particle invasion in various research areas [22, 23]. (See Fig. 1).

4. Antimicrobial activities of NPs

Silver is a well-known antibacterial agent used to combat pathogenic bacteria; it is used in the form of AgNPs. Silver has been found to be less harmful to animal cells while also having the best antibacterial properties of any metal. Silver is used in the form of nitrate for antibacterial effects, but silver nanoparticles (NPs) increase the surface area available to microbes. Cells are also killed when AgNPs generate free radicals, which is thought to be a separate process so far. AgNPs can emit silver ions when they interact with their thiol group, which inactivates many essential enzymes [24–26]. When silver and bacterial cells come into contact, the cells absorb silver ions, causing them to halt vital cell functions and harm the cell. Sulfur and phosphorus are present in cells, corresponding to the composition of soft bases. Cell death occurs as a result of NP responses [27]. Another reality is that phosphorus and sulfur are important components of DNA, which means that NPs can degrade these soft bases and disrupt the DNA, resulting in cell death. The interaction of phosphorus and sulfur in DNA with AgNPs disrupts bacterial DNA replication, killing the germs. Because silver ion has a positive charge, it is thought to be an effective antibacterial vital factor. Silver, in its ionized form, is antibacterial [28, 29]. Silver ions are more likely to interact with nucleosides than with nucleic acid phosphate groups; silver ions are inserted into the substance and slowly released with sulfadiazine; or silver ions can be created from a solid piece of silver, as with AgNPs. According to the literature, electrostatic attraction occurs when bacterial cells are negatively charged and NPs are positively charged, which is why it is proposed to be a more effective bactericidal agent [30, 31].

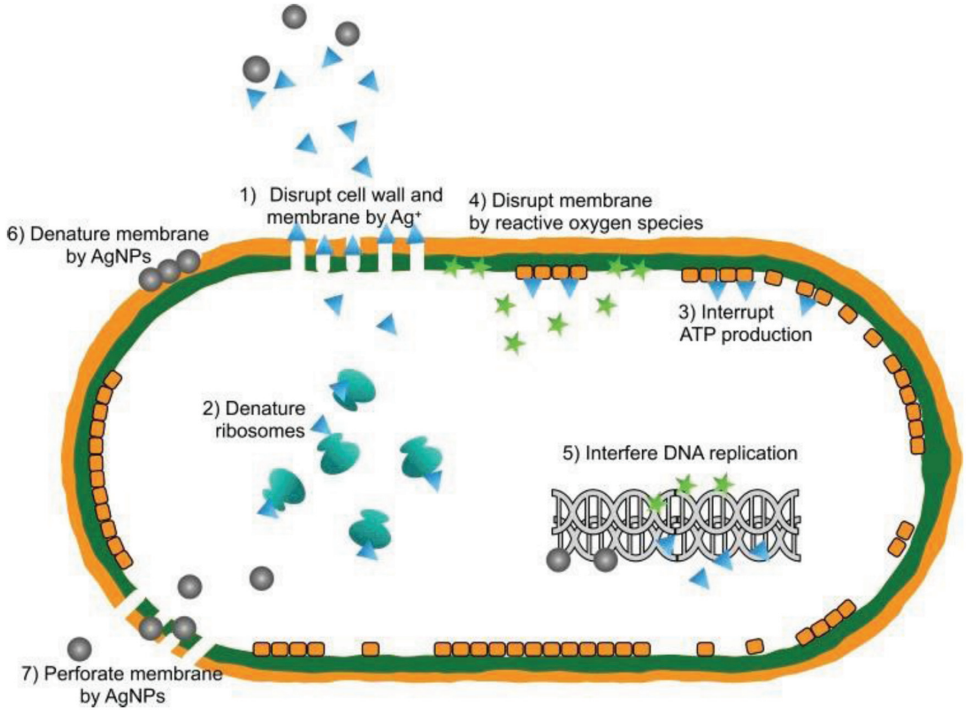

Fig. 2. Antimicrobial activities of NPs.

5. Antimicrobial mechanism of NPs

Silver is the most well-known antimicrobial metal used against microorganisms, particularly in the form of AgNPs. Silver in the form of nitrate is used for antibacterial purposes so it increases the surface area available for microbe adhesion [32]. AgNPs are used in dentistry to provide antibacterial materials that enhance the efficiency of the dental apparatus for a better treatment outcome Individuals can really be added to acrylic resins in prosthetic therapies for the manufacturing of removable dentures, composite resins in restorative treatment for direct restoration, irrigating solutions in root canal therapy, orthodontic adhesive materials, membranes for guided tissue regeneration in periodontal treatment, and titanium coating in dental implant treatment [33]. Silver ions can cling to the cell wall and cytoplasm membrane due to electrostatic attraction and affinity for sulfur proteins. The related ions can permeate the cytoplasm membrane, causing the bacterial envelope to rupture [34]. When available silver ions pass through the membrane, respiration enzymes are inhibited, resulting in oxygen radicals but interrupting with adenosine triphosphate initiation [35]. Reactive oxygen species can break down cellular membranes and alter deoxyribonucleic acid (DNA). So even though sulfur and phosphorus are essential components of DNA, interactions between silver ions and these elements can cause problems with DNA replication, cell reproduction, and even microorganism death. Furthermore, silver ions can inhibit protein synthesis by denaturing cytoplasmic ribosomes [36]. Although the actual mechanism of antibacterial activity of AgNPs is unidentified, several antibacterial actions have been proposed. AgNPs can consistently release silver ions, which can be considered a method for killing microorganisms (See Fig. 2).

AgNPs' antibacterial properties are affected by their size, biological influences, and coating agencies. AgNPs' toxicity and antibacterial activity are still being studied. The positive charge of silver ions is required for antibacterial activity. Because once silver is ionized, its antibacterial properties are enhanced. Silver is innocuous in its ionized form, but it releases silver ion when it comes into contact with humidity. Silver ions are introduced into the substance and slowly released with sulfadiazine, or silver ions can be generated from a solid piece of silver, as with AgNPs. According to the publications, electrostatic attraction occurs when bacterial cells are negatively charged and NPs are positively charged, and they are proposed to be a more effective bactericidal agent. Because NPs collect inside and penetrate cells, they generally cause cell membrane damage [37]. Silver maintain stable interactions with thiol-containing molecules, inactivating enzymes in the cell membrane and facilitating ion transport and transmembrane

Table 1. Silver nanoparticles are produced by fungal species.

No	Fungus	Size (nm)	Shape	Location
1	Aspergillus flavus	8.92	Sphereshaped	Cell wall
2	A. fumigatus	1.2–6.8	Sphereshaped	Extracellular
3	A. terreus	1–20	Sphereshaped	Extracellular
4	Cladosporium cladosporioides	10–100	Sphereshaped	Extracellular
5	Coriolus versicolor	25–75	Sphereshaped	Intra- and extracellular
6	Fusarium oxysporum	20–50	Sphereshaped	Extracellular
7	Macrophomina phaseolina	5–40	Sphereshaped	Cell-free filtrate
8	Pediococcus pentosaceus	10–30	Sphereshaped	Extracellular
9	Penicillium fellutanum	5–25	Sphereshaped	Extracellular
10	P. nagiovense	25 ± 2.8	Sphereshaped	Cell-free filtrate
11	Phoma glomerata	60–80	Sphereshaped	Extracellular
12	Pleurotus sajor caju	30.5	Sphereshaped	Extracellular
13	Trichoderma asperellum	13–18	Nanocrystalline	Extracellular
14	T. reesei	5–50	Sphereshaped	Extracellular
15	T. viride	5–40	Sphereshaped	Extracellular
16	T. harzianum	5–40	Sphereshaped	Extracellular

energy production. Introducing silver ions between pyrimidine and purine base pairs disrupts hydrogen bonding, tends to result in DNA denaturement. Whenever a bacterial cell ruptures, antibacterial drugs activity may occur when it enters the cell.

6. The NPs of fungi

One of the most studied issues in chemistry, physics, and material science is the self-assembly of NPs into nanostructured materials [38]. Fungal nanotechnology opens up new possibilities in medicine, biotechnology, and veterinary physiology, with more intriguing application fields in pathogen identification and treatment. Because it is simple, inexpensive, and more sustainable, myco-nanotechnology may be an excellent candidate for green NPs synthesis [39]. Myco-synthesis of NPs has the ability to be used in a variety of industries, which include medicine, and in a broad array of applications, including wound healing, drug delivery, cosmetics, food preservation, textile textiles, and so many more. Fungi show a vital potential in the biosynthetic pathway of NPs by secreting enzymes and proteins that reduce the production in the formation of metal NPs from metal salts. In recent decades, multiple technologies have been developed to increase the yield of NPs of various form, size, and stability [40]. Over the last two decades, alternative (green / biological) methods for producing different types of NPs have been initiated and broadly used. In these procedures, microorganisms, specifically intracellular or extracellular extracts of fungi or bacteria, are used. Because of their ease of growth and low cost on both the research and industrial scales, fungi are appealing candidates for huge synthesis of NPs [41]. This section will focus on nanobio-fungicides as environmentally sustainable options for pathogenic and toxigenic bacterial control, particularly in dentistry.

7. Production of AgNPs by fungi

The majority of traditional technologies for obtaining NPs have drawbacks, such as the use of hazardous chemicals and the production of trash, both of which can damage the environment. As a result, there has been a recent surge in interest in environmentally friendly synthesis processes. These methods rely on microorganisms like bacteria and fungi, which can degrade metal salts and produce NPs with the desired size and morphology. The generation of NPs via biological metal reduction is a safe, non-toxic, and environmentally friendly method [42]. Many filamentous fungi (over 28 genera and 54 species) can produce various kinds of NPs, with some (ten genera and sixteen species) producing silver NPs (See Table 1).

Many studies have been conducted on AgNPs produced by fungi, whether extracellularly or intracellularly. Even if the other parameters, such as aqueous solution $AgNO_3$, pH, and temperature, are the same, AgNPs produced by Aspergillus fumigatus may not have the same dimensions as those generated by Fusarium oxysporum. Incubation times can range between 15 and 60 minutes [43, 44]. But even though the synthesis of AgNPs from the fungus Trichoderma reesei takes 72 hours, it is ideal for large NP production. They varied in diameter from 5 to 50 nm. F. oxysporum produces AgNPs with diameters of 20–50 nm, which accumulate in spherical shapes [45] (See Fig. 3).

A nitrate dependent reductase enzyme and a shuttle quinone were used to reduce metal ions extracellularly. The production of extracellular and intracellular

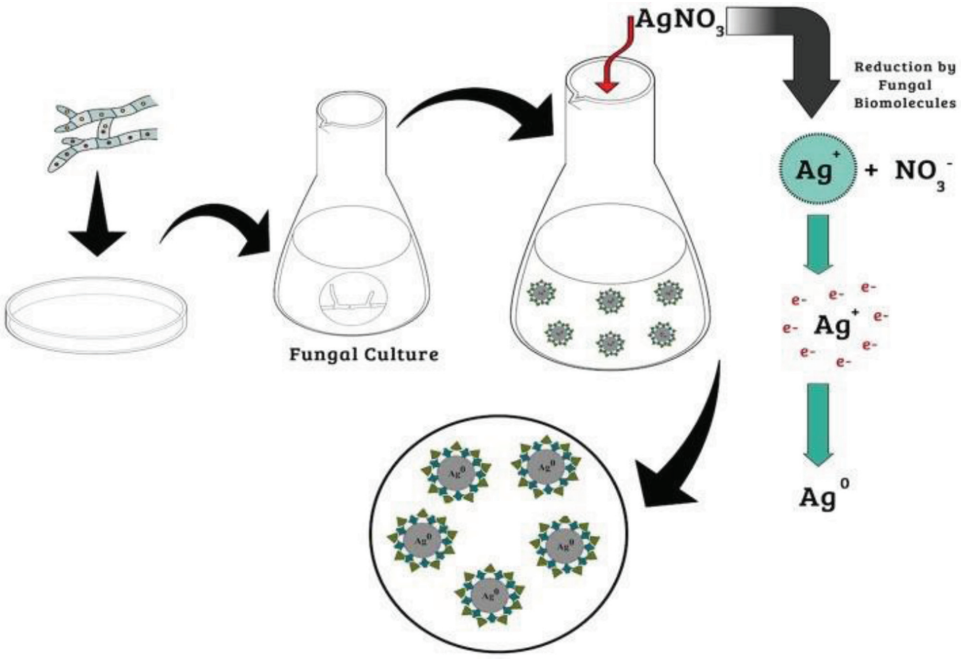

Fig. 3. Methods for biogenic synthesis of silver nanoparticles originating from fungi.

AgNPs in Coriolus versicolor, a white rot fungus, was analyzed. Extracellular AgNP synthesis has also been noticed in the fungi A. fumigatus and Phoma sp [46–48]. Furthermore, the fungus Trichoderma viride has been used to generate polydispersed AgNPs varying in size from 5 to 40 nm at around 27 °C. Because it is simple, inexpensive, and more reliable, myconanotechnology may be an ideal candidate for green NPs synthesis. AgNPs produced by fungi have low toxicity and high biocompatibility, and they can inhibit a wide range of diseases [49, 50].

8. Dental biofilm formation

Biofilms are microorganism accumulations (bacteria and fungi) that attach to biological and non-biological surfaces and organize themselves functionally in layers. To stay alive dehydration, organisms require a moist environment in which to form biofilms. The mouth cavity is a complex system that accumulates everything from food to saliva. To protect themselves from external stress in a specific environment, microorganisms form biofilms [51–53]. Biofilms play an important role in protecting the system from outside stimuli by secreting an extracellular polymeric substance (EPS). The most serious bacterial that occupy a washed tooth enamel are oral streptococci (particularly Streptococcus mutans) [54]. The formation of biofilms in the buccal cavity is a four-stage process that includes (a) acquired pellicle production, (b) primary (early) colonization, (c) secondary colonization / co-aggregation, and (d) mature biofilm formation Human saliva serves as the main source of nutrition for microbiome adhesion and allows for the covering of hard or soft surfaces with an acquired pellicle or conditioning film, which is a thin (5–10 m thickness), heterogeneous, and acellular pellicle. The first adherence bacteria (Streptococcus sanguinis, Streptococcus oralis, Streptococcus gordonii, Streptococcus mitis, Streptococcus mutans, and Streptococcus sobrinus, Actinomyces naeslundii) are shallowly and reversibly connected to the acquired pellicle by adhesins, but they may stay and prolife Steptococcus spp. account for 60–80% of all primary colonizers [55, 56].

The oral cavity is an unique system that accumulates a range of chemical such as food, saliva, oral biofilms, and their metabolites. Oral biofilms are well-organized bacteria colonies that adhere to teeth, dental restorative structures, or oral soft tissues and are enveloped by a polysaccharide-based matrix containing nucleic acids, proteins, and H_2O. As a result, the pH in the oral cavity is frequently altered, reaching low levels after the usage of acidic substances and/or the production of acids via oral microbial activity. After consuming warm or cold foods, the temperature fluctuates temporarily. Further to that, there is a fluctuation in CO_2 concentration in the oral cavity, as evidenced by the presence or absence of oxygen content in areas below the gingival border. As a result, changes in oxygen and pH impact microbes colonization inside the mouth, promoting the

preferential progression of anaerobic or aerobic bacteria [57–60].

9. The fungal NPs and oral biofilms control

Anti-plaque agents, in general, work by destroying biofilms or avoid the formation of new biofilm communities. The absorption and penetration of antimicrobial drugs into biofilms are critical considerations in therapeutic delivery. It is critical to develop biofilm control strategies that require little patient compliance and professional healthcare intervention [61, 62]. AgNPs produced by fungi have low toxicity and high biocompatibility, permitting them to inhibit infections. These findings pave the way for additional research into the use of these nanoparticles as antimicrobials in the fields of health and dentistry [63, 64]. Antimicrobial NPs may be of particular interest in this section; however, the possibility of fungal NPs as constituents of topical treatments to control oral biofilms via biocidal or anti-adhesive characteristics has recently emerged as an area that should be seriously considered [65–67]. The lethality of AgNPs is chiefly attributed to presence of chemical and/or biological paints on the NPs surface, which interact with the cell wall and elicit progressive metabolic retorts, along with the generation of reactive oxygen species oxygen [68–72]. The oral cavity encourages the production of a wide variety of microorganisms, which include bacteria and yeasts, which are linked with oral illnesses as biofilms. The use of AgNPs with biocidal and antiadhesive properties allows for the control of the formation of oral biofilms via the use of nanotechnology [73–75]. Several other NPs, in addition to silver, like as copper oxide, zinc oxide NPs, titanium oxide, and graphene, can be used to begin regulating bacterial colonization [76, 77]. Often used as a dentine coating, silver nano-coating directly on dentine can effectively prevent biofilm formation on dentinal tubules surfaces and restricts bacterial growth in the neighboring regions, intimating a dependable strategy for defending against dental plaque and peripheral caries. S. mutans and L. acidophilus acidophilus biofilms were dramatically lowered by these nanoparticles [78, 79]. Coating tooth surfaces with antibacterial nanocoating was found to be effective in stopping the growth of bacteria, diminishing bacterial attachment, and ensure the integrity of the enamel surface when biofluids were engaged (saliva) [80, 81]. These Nanomaterials' antibacterial activity was discovered to be size dependent [82]. Several nanoparticles (NPs) have been used as antibacterial nanotherapy, most notably AgNPs, which have been assimilated into dental composites or dental adhesives to limit bacterial growth and biofilm development through a variety of mechanisms [83–85]. These pathways include bacterial cell membrane disruption, decreased expression of road transport and glucose metabolism, the production of reactive oxygen species, the displacement of magnesium ions required for oral biofilm enzymatic activity, unrest of electron transport across the bacterial cell membrane, and the minimization of DNA replication [86, 87].

10. Factors affecting biosynthesis of AgNPs

Because of their widespread usage in fields such as nanomedicine, AgNPs are in high demand. Innovative techniques for synthesizing AgNPs that use environmentally friendly reagents and solvents are required. In order to validate a good synthesis of AgNPs, it is important to have a look for acceptable production settings. Because they are more environmentally friendly, green strategies are the most commonly used in this industry [88]. The nanoparticles synthesized by fungus was investigated under a variety of physicochemical conditions, including $AgNO_3$ concentration, pH, time, and temperature [89]. Different sizes of AgNPs were formed when a neutral pH fungal cell filtrate was introduced to varying amounts of aqueous solution $AgNO_3$ (1–10 mM). As the density of $AgNO_3$ (9–10 mM) increases, the size of the AgNPs increases. The size of the AgNPs, however, diminished as alkaline conditions raised. Temperature has varying effects on the size of NPs. As the temperature increased, the size of the AgNPs shrank.

When an organic solvent of 1 mM $AgNO_3$ with fungal cell permeate with a neutral pH was applied to multiple temperature levels (10, 30, 50, 70, and 90 °C), various sizes of AgNPs were established.

11. Conclusion

Because the antimicrobial resistance in oral health, researchers are putting a lot of effort into trying to identify alternative agents for controlling oral biofilms. AgNPs hold great promise as biocidal and anti-adhesive agents against oral biofilms. The importance of targeting oral biofilms with precision, effectiveness, and efficiency is emphasized. Recent research indicates that biogenic synthesis of AgNPs using fungi has a number of advantages and that these materials have a lot of potential in the field of dental hygiene. Novel nanoparticles, which can carry antimicrobial medications or act as therapeutic agents in their own right, can accurately target bacteria in response to a particular environmental factor. The capacity to use various fungi species and perform the synthesis under different conditions enables

the production of AgNPs with a variety of physicochemical properties. Fungus produces the capping on the AgNPs, which provides stability. Advances in nanotechnology are paving the way for the future of healthcare management, particularly in dentistry. According to the articles that have been published thus far, using fungi for biogenic production of AgNPs has a wide spectrum of applications. Various variables, such as substrate ($AgNO_3$) concentration, duration, pH, and temperature, have also been demonstrated to influence fungus biosynthesis of AgNPs. AgNPs have a great deal of potential for use in the treatment of oral harmful bacteria.

Metallic nanoparticles begin to produce silver ions (Ag+), which attach to or colonizes the cell membrane and cell surface. (2) Denaturement of ribosomes: Silver ions denature ribosomes, resulting in a decrease in protein production. (3) Adenosine triphosphate (ATP) production suppression: Silver ions constrain the respiratory enzyme on the cytoplasmic membrane, restricting ATP synthesis. Cell wall disruption as a result of reactive oxygen species produced by a broken electron transport chain: Membrane disruption can occur as a result of reactive oxygen species produced by a destroyed electron transport chain. (5) DNA replication interaction: Silver and reactive oxygen species bind to deoxyribonucleic acid, blocking proliferation and cell growth. (6) Membrane denaturation occurs when nanoparticles collect and cause membrane conformational changes in cracks in cell membranes. (7) Penetration of silver of the membrane nanoparticles penetrate right through the cell membranes, letting organelles to exit the cell.

References

1. Bowen W, *et al.* Oral biofilms: pathogens, matrix, and polymicrobial interactions in microenvironments. Trends in Microbiology 2018;26(3):229–42. doi:10.1016/j.tim.2017.09.008.
2. Ottoni CA, *et al.* Screening of filamentous fungi for antimicrobial silver nanoparticles synthesis. AMB Expr 2017;7:31–41.
3. Schmalz B, *et al.* Scientific update on nanoparticles in dentistry. International Dental Journal 2018;68:299–305. doi:10.1111/idj.12394.
4. Besinis A, *et al.* Inhibition of biofilm formation and antibacterial properties of a silver nano-coating on human dentine. Nanotoxicology 2014;8 (7):745–754. doi:10.3109/17435390.2013.825343.
5. Van Acker *et al.* Molecular mechanisms of antimicrobial tolerance and resistance in bacterial and fungal biofilms. Trends in Microbiology 2014;22(6):326–33. doi:10.1016/j.tim.2014;02.001.
6. Centre for Disease Control. Infection prevention & control in dental settings. 2019; Available at: http://www.cdc.gov/OralHealth/infectioncontrol/index.html.
7. Hossain Z, *et al.* Nanoparticles: synthesis, morphophysiological effects, and proteomic responses of crop plants. International Journal of Molecular Sciences 2020;21(9):3056.
8. Tortella H., *et al.* Silver nanoparticles: toxicity in model organisms as an overview of its hazard for human health and the environment. J Hazard Mat 2020;390:121974.
9. Abou Neel A, *et al.* Nanotechnology in dentistry: prevention, diagnosis, and therapy. International Journal of Nanomedicine 2015;10:6371–94.
10. Subhashree P, *et al.* Nanoparticles used in dentistry: a review. J Oral Biol Craniofac Res 2018;8(1):58–67. doi:10.1016/j.jobcr.2017.12.004.
11. Lüdecke C, *et al.* Nanorough titanium surfaces reduce adhesion of escherichia coli and staphylococcus aureus via nano adhesion points. Colloids Surf B Biointerfaces 2016;145:617–25.
12. Kulshrestha S, *et al.* A grapheme/zinc oxide nanocomposite film protects dental implant surfaces against cariogenic Streptococcus mutans. Biofouling 2014;30:1281–94.
13. Eshed M, *et al.* MgF 2 nanoparticle-coated teeth inhibit Streptococcus mutans biofilm formation on a tooth model. J Mater Chem B 2013;1:3985–91.
14. AlKahtani RN, *et al.* The implications and applications of nanotechnology in dentistry: a review Saudi Dent J 2018;30(2):107–16. doi:10.1016/j.sdentj.2018.01.002.
15. Popescu M, *et al.* Biogenic production of nanoparticles. Dig J Nanomater Bios 2010;5(4):1035-40.
16. Hossain Z, *et al.* Nanoparticles: synthesis, morphophysiological effects, and proteomic responses of crop plants. International Journal of Molecular Sciences 2020;21(9):3056.
17. Beyene HD, *et al.* Synthesis paradigm and applications of silver nanoparticles (AgNPs), a review. Sustainable Mater Technol 2017;13:18–23.
18. Prabhu S, Poulose EK. Silver nanoparticles: mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. International Nano Letters 2012;2(1):32.
19. Li Y, Boraschi D. Endotoxin contamination: a key element in the interpretation of nanosafety studies. Nanomedicine (Lond) 2016;11:269–87.
20. Khan I, Saeed K. Nanoparticles: properties, applications and toxicities. Arabian journal of chemistry. 2019;12(7):908–31.
21. Rai MK, *et al.* Silver nanoparticles: the powerful nanoweapon against multidrug-resistant bacteria. Journal of Applied Microbiology 2012;112(5):841–52. doi:10.1111/j.1365-2672.2012.05253.x.
22. Khurshid Z, *et al.* Advances in nanotechnology for restorative dentistry. Materials 2015;8:717–31.
23. Klaus DJ, David CW. Nanotechnology in dentistry: present and future perspectives on dental nanomaterials. Dent Mater 2020;36(11):1365–78.doi:10.1016/j.dental.2020.08.0064.
24. Kim JS, *et al.* Antimicrobial effects of silver nanoparticles. Nanomedicine 2007;3:95–101.
25. Sotiriou GA, Pratsinis SE. Antibacterial activity of nanosilver ions and particles. Environ Sci Technol 2010;44:5649–54.
26. Rai MK, *et al.* Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv 2009;27:76–83.
27. Emmanuel R, *et al.* Antimicrobial efficacy of green synthesized drug blended silver nanoparticles against dental caries and periodontal disease causing microorganisms. Mater Sci Eng C Mater Biol Appl 2015;56:374–9.
28. Pérez-Díaz MA, *et al.* Silver nanoparticles with antimicrobial activities against Streptococcus mutans and their cytotoxic effect. Mater Sci Eng C Mater Biol Appl 2015;55:360–6.
29. Corrêa JM, *et al.* Silver nanoparticles in dental biomaterials. Int J Biomater 2015:2015.
30. Lewisoscar AB, *et al.* In vitro analysis of green fabricated silver nanoparticles (AgNPs) against Pseudomonas aeruginosa PA14 biofilm formation, their application on urinary catheter. Progress in Organic Coatings 2021;151:106058.
31. Park HJ, *et al.* Biofilminactivating activity of silver nanoparticles: a comparison with silver ions. Ind Eng Chem Res 2013;19:614–19.
32. Ramachandran R, Sangeetha D. Antibiofilm efficacy of silver nanoparticles against biofilm forming multidrug resistant clinical isolates Pharma Innov J 2017;636.
33. Bapat RA, *et al.* An overview of application of silver nanoparticles for biomaterials in dentistry. Mater Sci Eng C 2018;91:881–98. doi:10.1016/j.msec.2018.05.069.

34. Khorrami S, *et al.* Selective cytotoxicity of green synthesized silver nanoparticles against the MCF-7 tumor cell line and their enhanced antioxidant and antimicrobial properties. Int J Nanomedicine 2018;13:8013–24. doi:10.2147/IJN.S189295.
35. Ramkumar VS, *et al.* Biofabrication and characterization of silver nanoparticles using aqueous extract of seaweed Enteromorpha compressa and its biomedical properties. Biotechnol Rep 2017;14:1–7. doi:10.1016/j.btre.2017.02.001.
36. Durán N, *et al.* Antimicrobial activity of biogenic silver nanoparticles, and silver chloride nanoparticles: an overview and comments. Appl Microbiol Biotechnol 2016;100(15):6555–70. doi:10.1007/s00253-016-7657-7.
37. Iris XY, *et al.* The antibacterial mechanism of silver nanoparticles and its application in dentistry. Int J Nanomedicine 2020;15:2555–62. doi:10.2147/IJN.S246764.
38. Polte, J, *et al.* Mechanism of gold nanoparticle formation in the classical citrate synthesis method derived from coupled in situ XANES and SAXS evaluation. J Am Chem Soc 2010;132:1296–301.
39. Mahendra R, *et al.* Fusarium as a novel fungus for the synthesis of nanoparticles: mechanism and applications. J Fungi 2021;7(2):139. doi:https://doi.org/10.3390/jof7020139.
40. Shadia M, *et al.* Fungal nanoparticles: a novel tool for a green biotechnology? Fungal Nanobionics: Principles and Applications 2018;61-87.
41. Balasooriya, ER, *et al.* Honey mediated green synthesis of nanoparticles: new era of safe nanotechnology. J Nanomater 2017;5919836. https://doi.org/10.1155/2017/5919836. doi:https://doi.org/10.3389/fbioe.2019.00287.
42. Mariana GC, Renata de L. Synthesis of silver nanoparticles mediated by fungi: a review. Front Bioeng Biotechnol 2019. doi:https://doi.org/10.3389/fbioe.2019.00287.
43. Bhainsa KC and D'Souza SF. Extracellular biosynthesis of silver nanoparticles using the fungus Aspergillus fumigatus. Coll Surf B Biointerfaces. 2006;47:160–4.
44. Ahmad A, *et al.* Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium oxysporum. Coll Surf B Biointerfaces 2003;28:313–18.
45. Durán N, Marcato PD, Alves OL, DeSouza G, Esposito E. Mechanistic aspects of biosynthesis of silver nanoparticles by several Fusarium oxysporum strains. J Nanobiotechnol 2003;3:1–8.
46. Elkhateeb *et al.* Nanoparticles: characterization, biological synthesis and applications. J Microbiol Biotechnol. 2021;6(2):000196. doi:10.23880/oajmb-16000196.
47. Bhainsa KC, D'Souza SF. Extracellular biosynthesis of silver nanoparticles using the fungus Aspergillus fumigatus. Coll Surf B Biointerfaces 2006;47:160–4.
48. Elamawi, *et al.* Biosynthesis and characterization of silver nanoparticles using Trichoderma longibrachiatum and their effect on phytopathogenic fungi. Egyptian Journal of Biological Pest Control 2018;28:28. doi:10.1186/s41938-018-0028-1.
49. Fayaz M, *et al.* Blue orange light emission from biogenic synthesized silver nanoparticles using Trichoderma viride. Coll Surf B Biointerfaces 2010;75:175–8.
50. Mahendra R, *et al.* Fusarium as a novel fungus for the synthesis of nanoparticles: mechanism and applications. J Fungi 2021;7(2):139. doi:https://doi.org/10.3390/jof7020139.
51. Marsh PD. Dental plaque: biological significance of a biofilm and community life-style. J Clin Periodontol 2005;32(Suppl 6):7–15.
52. Engel A, *et al.* Biofilm formation on different dental restorative materials in the oral cavity. BMC Oral Health 2020;20:162. doi:https://doi.org/10.1186/s12903-02001147-x.
53. Chia N, *et al.* A collective mechanism for phase variation in biofilms. Proc Natl Acad Sci USA 2008;105(38):14597–602.
54. Hall-Stoodley, *et al.* Bacterial biofilms: from the natural environment to infectious diseases. Nat Rev Microbiol 2004;2(2):95–108.
55. Kolenbrander PE, *et al.* Communications among oral bacteria. Microbiol Mol Bio Rev 2002;66:486–505.
56. Teughels W, *et al.* Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res 2006;17:68–81.
57. Belibasakis GN, *et al.* Periimplant infections of oral biofilm etiology. Adv Exp Med Biol 2015;830:69–84.
58. Souza JCM, *et al.* Biofilms inducing ultra-low friction on titanium. J Dent Res 2010a;89:14701475.
59. Souza JCM, *et al.* Corrosion behaviour of titanium in the presence of Streptococcus mutans. J Dentistry 2013;41:528-34.
60. Souza JCM, *et al.* Biofilm Formation on different materials used in oral rehabilitation. Brazilian Dental Journal 2016;27(2):141147. doi.org/10.1590/01036440201600625.
61. Parnia F, *et al.* Overview of nanoparticle coating of dental implants for enhanced osseointegration and antimicrobial purposes. J Pharm Pharm Sci 2017;20:148–60.
62. Stewart PS. Diffusion in biofilms. J Bacteriol 2003;185:1485–91.
63. Burdușel AC, *et al.* Biomedical applications of silver nanoparticles: an up-to-date overview. Nanomaterials. 2018;8:E681. doi:10.3390/nano8090681.
64. Maliszewska I, *et al.* Green synthesis and characterization of silver nanoparticles using ascomycota fungi Penicillium nalgiovense AJ12. J Clust Sci 2014;25:989–1004.
65. Robert PA, Zhiyu Y. Nanoparticles and the control of oral biofilms. Nanobiomaterials in Clinical Dentistry 2019:243–75. doi:10.1016/B978-0-12815886-9.00010-3.
66. Xi-Feng Z, *et al.* Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. Int J Mol Sci 2016;17(9):1534. doi:10.3390/ijms17091534.
67. Abdelmageed MO, *et al.* Biosynthesis and characterization of silver nanoparticles induced by fungal proteins and its application in different biological activities. J Genet Eng Biotechnol 2020;11;18:7. doi:10.1186/s43141-0190008-1.
68. Gudikandula K, *et al.* Biogenic synthesis of silver nanoparticles from white rot fungi: their characterization and antibacterial studies. Open Nano 2:64–78. 10.1016/j.onano.2017.07.002.
69. Siddiqi KS, Husen A. Fabrication of metal nanoparticles from fungi and metal salts: scope and application. Nanoscale Research Letters 2016;11:98. doi:10.1186/s11671-016-1311-2.
70. Suresh AK, *et al.* Cytotoxicity induced by engineered silver nano-crystallites is dependent on surface coatings and cell Types. Langmuir 2012;28:2727–35. doi:10.1021/la2042058.
71. Porter GC, *et al.* Anti-biofilm activity of silver nanoparticle-containing glass ionomer cements. Dent Mater 2020;36:1096–107.
72. Robert PA, Zhiyu Y. Nanoparticles and the control of oral biofilms. Nanobiomaterials in Clinical Dentistry. 2019:243–275. doi:10.1016/B978-0-12815886-9.00010-3.
73. Xinyi K, *et al.* Approaches to the control of oral microbial biofilms. Biomed Res Int 2018;6498932. Published online. doi:10.1155/2018/6498932.
74. Allaker RP, Memarzadeh K. Nanoparticles and the control of oral infections. International Journal of Antimicrobial Agents 2014;43(2):95–104. doi:10.1016/j.ijantimicag.2013.11.002.
75. Gao L, Koo H. Do catalytic nanoparticles offer an improved therapeutic strategy to combat dental biofilms? Nanomedicine 2017;12(4):275–9. doi:10.2217/nnm-2016-0400.
76. Al-Kalifawi EJ, *et al.* Antibacterial, antivirulence and antifungal activity of silver nanoparticles synthesized using alkhal mother shae. Journal of Physics: Conference Series 1879/022054, 2020. doi:10.1088/17426596/1879/2/022054.
77. Hemeg HA. Nanomaterials for alternative antibacterial therapy. International Journal of Nanomedicine 2017;12:8211–25. doi:10.2147/IJN.S132163.
78. Besinis A, *et al.* Inhibition of biofilm formation and antibacterial properties of a silver nanocoating on human dentine. Nanotoxicology 2014;8(7):745–54. doi:10.3109/17435390.2013.825343.
79. Shrestha A, *et al.* Nanoparticulates for antibiofilm treatment and effect of aging on its antibacterial activity. Journal of Endodontics 2010;36(6):1030–5. doi:10.1016/j.joen.2010.02.008.

80. Wu D, *et al.* Evaluation of the antibacterial efficacy of silver nanoparticles against Enterococcus faecalis biofilm. Journal of Endodontics 2014;40(2):285–90. doi:10.1016/j.joen.2013.08.022.
81. Cheng L, *et al.* Anti-biofilm dentin primer with quaternary ammonium and silver nanoparticles. Journal of Dental Research 2012;91(6):598–604. doi:10.1177/0022034512444128.
82. Lu Z, *et al.* Size-dependent antibacterial activities of silver nanoparticles against oral anaerobic pathogenic bacteria. J Mater Sci Mater Med 2013;24(6):1465–71.
83. Omanović-Mikličanin E, *et al.* Nanocomposites: a brief review. Health Technol 2020;10:51–9.
84. Genari B, *et al.* Antimicrobial effect and physicochemical properties of an adhesive system containing nanocapsules. Dent Mater 2017;33:735–42.
85. Porter GC, *et al.* Anti-biofilm activity of silver nanoparticle-containing glass ionomer cements. Dent Mater 2020;36:1096–107.
86. Ranjani S, *et al.* Synthesis, characterization and applications of endophytic fungal nanoparticles. Inorganic and Nano-Metal Chemistry 2021;51(2):280–7. doi:https://doi.org/10.1080/24701556.2020.1784231.
87. Mohana S, Sumathi S. A mini review on fungal based synthesis of silver nanoparticles and their antimicrobial activity. Int J Chem Tech Res 2017;10:367–77.
88. Othman AM, *et al.* Biosynthesis and characterization of silver nanoparticles induced by fungal proteins and its application in different biological activities. J Gen. Eng Biotechnol 2020;11:18–27. doi:10.1186/s43141-0190008-1.
89. Phanjom P, Ahmed G. Effect of different physicochemical conditions on the synthesis of silver nanoparticles using fungal cell filtrate of Aspergillus oryzae (MTCC No. 1846) and their antibacterial effect. Adv Nat Sci Nanosci Nanotechnol 2017;8:045016.