Nanoparticles and Its Applications in Toothpaste Preparation

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Abstract- Nanotechnology deals with the manufacture of particles, materials, or structures of molecules with dimensions on the nanometer level. Healthcare nanoparticles (NPs) have become prevalent in several aspects of dentistry, particularly prevention, diagnosis, treatment, and repair, according to several research. The use of nanoparticles in dental cosmetics improves the effectiveness of mouthwash as well as toothpaste. Toothpaste contains nanoparticles for multiple purposes, such as preventing dental decay, remineralizing the tooth enamel, decreasing hypersensitivity, whitening the tooth, and possessing antimicrobial properties. This study aims to give a better understanding of the applications of nanoparticles in toothpaste preparation and dentistry. The nanoparticles which were explored include silver, Hydroxyapatite (HAp), calcium, gold, zinc and selenium. In this study, rising trends in nanoparticle's field and based on the novel NPs approaches, possible future prospects of nanoparticle-based toothpaste formulation were also discussed.

Keywords: Nanotechnology, toothpaste, silver nanoparticles, HAP, gold nanoparticles, calcium nanoparticles, selenium nanoparticles, zinc nanoparticles.

INTRODUCTION

Typically, one would describe Nano Particles (NPs) as minuscule particles, ranging in size from 1 to 100 nm, possessing characteristics not found in larger samples of the same material (Auffan et al., 2009). Human activity is the cause of both artificially created and naturally occurring nanoparticles. Manufactured nanoparticles have numerous potential applications in engineering, medicine, environment, and catalysis, among other domains, because of their tiny size and distinctive material characteristics. Some research studies indicate the main criteria for any definition of nanoparticles ought to involve their distinct size-dependent properties only, not their particle size (Gronwald et al., 2023). NPs are great carriers for dental applications because of a variety of unique qualities, including their surface-to-volume ratio, antibacterial activity, physical, mechanical, and biological properties, and varied particle sizes (Bapat et al., 2019). Through acute toxicity processes, inorganic nanoparticles can localize bioactive molecules to the target locations and protect them from degradation; nevertheless, over time, these materials may represent significant health problems because of their long-term toxicity. Planning research that use NPs requires a deeper understanding of the subject and caution, given the increased interest in their use (Gronwald et al., 2023).

Toothpaste is a partially solid gel substance that is used with a toothbrush to keep teeth in a good state, encourage dental care, and stop decay and discolouration. Generally, toothpastes have these ingredients: Abrasive materials such as Haps (hydroxyapatite), calcium carbonate, silica, and aluminum hydroxide; Anticaries agents such as sodium bicarbonate, xylitol, calcium and phosphate supplement, and Fluoride (1450 ppm in the form of sodium fluoride, stannous fluoride, and sodium fluorophosphate); Antibacterial agents such as fluoride, silver, zinc chloride, triclosan, stannous cation, and herbal essential oils ; anti-plaque agents such as sodium lauryl sulfate, triclosan, stannous-ions, zinc-ions, chlorhexidine; Whitening agents such as papain, sodium bicarbonate, and abrasive material; solvents (about 20–40 % w/w, such as water and alcohol ; surfactant or foaming agents such as sodium lauryl sulfate, and sodium lauryl sacrosinate; ; Antisensitivity agents such as arginine, potassium nitrate, and strontium chloride; Anticalculus agents such as zinc citrate, pyrophosphate, ureates, and sodium polyphosphate; Sweeteners such as xylitol, glycerol, sodium saccharin, and sorbitol (Abedi et al., 2024).

Enhanced mouthwash and toothpaste made possible by nanotechnology may play an important role in hindering dental disease (R.N. AlKahtani et al., 2018). As for "nanomaterials," they are solid systems with nanodomains encased in a large, thick matrix; this kind of arrangement should be distinguished from "free" NPs, which are often produced as solid, dispersed colloidal fragments. Both types of NPs are used in dental hygiene items that involve liquid dispersions like mouthwash or solid materials like toothpaste, where component stability throughout manufacturing and aging is crucial (Abedi et al., 2024).

TOOTHPASTE

Toothpaste is a paste or gel dentifrice which, when used in conjunction with a toothbrush, can help to maintain and improve oral health as well the teeth's appearance. Toothpaste has come a long way since its initial development thousands of years ago. We've seen that the simple suspension types, containing ashes or even broken egg shells have evolved into much more complex formulas often including well over 20 individual ingredients. It refers to products that should be used to help, prevent and reduce the development of gum disease, tooth decay, calculus formation and erosion or/and reduces dentine hypersensitivity. Furthermore, tooth pastes contain scents to provide the breath a fresh smell, coloring agents which enhance aesthetic appearance and cleaning abrasive reduce staining on the teeth. Toothpastes with maximum bioavailability of active ingredients are considered effective.

The most complex healthcare product is perhaps a toothbrush. A hydrocolloid is typically employed for the purpose of suspending an abrasive or mixture of abrasives in such an aqueous humectant phase. This matrix also includes penetration-enhancing substances, active (i.e., medicinal) agents, flavors and sweetening products, colorants as well as preservatives amongst other excipients.

Saliva acts as the slurry medium during brushing and the mechanical action of the toothbrush contributes to create a slurry from toothpaste slurry production, beyond facilitating active substances to mix in the oral cavity, will also allow for a certain ingredient concentration lowering; Consequently, the more diluted our slurry is, lower this. In addition, saliva may cause the slurry's temperature increase, alter the pH because of its buffering properties (less so for toothpaste with a strong buffer, such as sodium bicarbonate pastes), and allow saliva's constituent proteins and calcium to react with toothpaste excipients. (Lippert et al., 2013).

There are several toothpaste formulas available on the market. The inclusion of particle abrasives to toothpaste is crucial for its cleaning efficacy. Toothpaste contains a wide variety of abrasives, including as sodium bicarbonate, calcium carbonate, hydrated silica, calcium phosphates, perlite, and alumina. Up to 20% quantities of calcium carbonate as well as hydrated silica are employed. The relative hardness ratings of various abrasives vary, that in turn influences their abrasion abilities and cleaning efficiency. As they are hard, materials like perlite and alumina, for instance, are utilized as polishing compounds in small amounts of 1 to 2%. Many toothpaste formulas for teeth whitening incorporate a combination of various abrasives (Sarembe et al., 2023).

Using contemporary toothpaste is necessary for controlling gum disease and dental cavities (Unterbrink et al., 2024). There are many ways of preventing caries since the acids which trigger caries are created by cariogenic bacteria found in plaque on the surface of the tooth (Meyer et al., 2024). In addition to cleaning teeth, toothpastes now effectively fight erosion, lessen sensitivity, increase demineralization, lessen caries, strengthen gums, and, in certain cases, whiten teeth.

Of all the active components found in toothpaste, fluoride has the most research supporting it. Fluoride toothpaste has been shown in several systematic reviews to have a caries-preventive impact (Parnell et al., 2013). The most widely used source of fluoride is sodium fluoride (NaF), however, sodium monofluorophosphate (Na_2PO_3F) and stannous fluoride (SnF) can also be utilized (Okeke et al., 2024). Especially at low pH levels, fluoride ions can infiltrate bacteria cells, reduce acid formation in plaque and inhibit multiplication of germs. For dental health, people are encouraged to brush teeth with toothpaste that has fluoride for two minutes, preferably twice a day, to avoid gum diseases and tooth decay. By using the right procedure and amount of medication it can remineralize teeth by strengthening their surface, i.e. enamel through its antimicrobial activity when employed as above (Griffin et al., 2007; O Mullane et al., 2016). The maximum amount of fluoride compounds which can be employed in oral hygiene products is determined to be 1500 parts per million or 0.15% fluoride. Humans can die from sodium fluoride at concentrations of fifteen mg/kg (Comber et al., 2011).

TABLE 1: ACTIVE AGENTS IN TOOTHPASTE

AGENT	EFFECT
Fluoride, Remin systems e.g. CCP-ACP	Anti-caries
Triclosan/copolymer (Gantrez)	Anti-plaque/anti-calculus
Chlorhexidine	Anti-plaque/anti-gingivitis
Metal salts (tin and zinc, strontium)	Anti-caries/anti-plaque/anti-calculus/ desensitising
Pyrophosphates	Anti-calculus
Enzymes,peroxide,sodium hexametaphosphate, sodium tripolyphosphate	Whitening agents
Potassium nitrate/citrate/chloride, arginine/calcium carbonate, calcium sodium phosphosilicate	Desensitizing
Adopted from (Davies et al., 2010)	

NANOPARTICLES AND ITS DENTAL APPLICATIONS

The definition of nanotechnology is the manufacture of particles, materials, or structures of molecules with dimensions on the nanometer level. Such materials have many possible applications because of their bioactivity, the ability to dissolve, and antimicrobial properties when compared with macroscopic objects. As a result, NPs are among the most commonly employed nanomaterials in various fields because their characteristics, such as size, shape, surface chemistry, water-solubility, etc., can be adjusted during synthesis. Usually, NPs can be identified as carbon nanotubes, fullerenes, metallic NPs, polymeric NPs, and ceramic NPs. Numerous fields have discovered use for nanoparticles, including dentistry (particularly concerning dental implants and fillings), polishing enamel surfaces, preventing cavities, and teeth whitening (Mamidi et al., 2023).

Since nanoparticles have a smaller particle size and are capable of producing cell lysis, they are employed in a variety of dental applications, including local anaesthesia, hypersensitivity, treatment of cancer, and cancer diagnostics. Nanofibers and nanoneedles are two of the many kinds of nanoparticles that are employed in wound dressings (Shalumon et al., 2011). Due to their tiny size and ease of penetration, they have more surface area to cover than other particles and are capable of interacting with microbial membranes to hinder the formation of biofilm, which in turn leads to a reduction in the development of caries. These properties include antibacterial, anti-adhesive, cationic, and biocidal effects (Mary et al., 2023).

Dentifrobots have made it possible to heal hypersensitivity permanently, restore teeth to their original state, see instant benefits from orthodontic treatment, and remineralize enamel, all of which contribute to maintaining good oral hygiene. Since their particle sizes are lesser than those of other materials, nanoparticles find application in dental products, topical agents, and device coverings (Allaker et al., 2010, Ahn et al, 2009). For instance, composite materials use silver nanoparticles' antibacterial qualities, while toothpaste and mouthwashes use silver zeolite (Boldyryeva et al., 2005).

In comparison to other nanoparticles, zinc and silver particles demonstrate superior antimicrobial activity because of their smaller particle sizes, which enable them to permeate the cell membrane and cause cell lysis (Kassaee et al., 2008). Because oral diseases are more likely to result from bacterial growth in dentures, retainers, and other removable appliances, a lower percentage of silver and zinc nanoparticles are integrated into the acrylic resin polymer and acrylized, which is used in removable devices and acrylic base plates for dentures (Lee et al., 2008).

Since the nanoparticles possess antibacterial characteristics, they are utilized in restorative dentistry, cements, fiber posts, cavity liners, pit and fissure sealants, and cements to remineralize the tooth and improve treatment efficacy (Mirsasaani et al., 2011). Alginate impression powders combined with water containing silver hydrosol may generate an impression medium with antimicrobial qualities that minimize microbial cross-contamination to the poured stone model from the sick impression. Nanoparticles are introduced to the imprint substance due to their hydrophilic properties and ability to enhance the flow of the material. Similarly, to enhance tooth detailing, nano-fillers are applied to polyvinyl siloxane polymers (Mary et al., 2023).

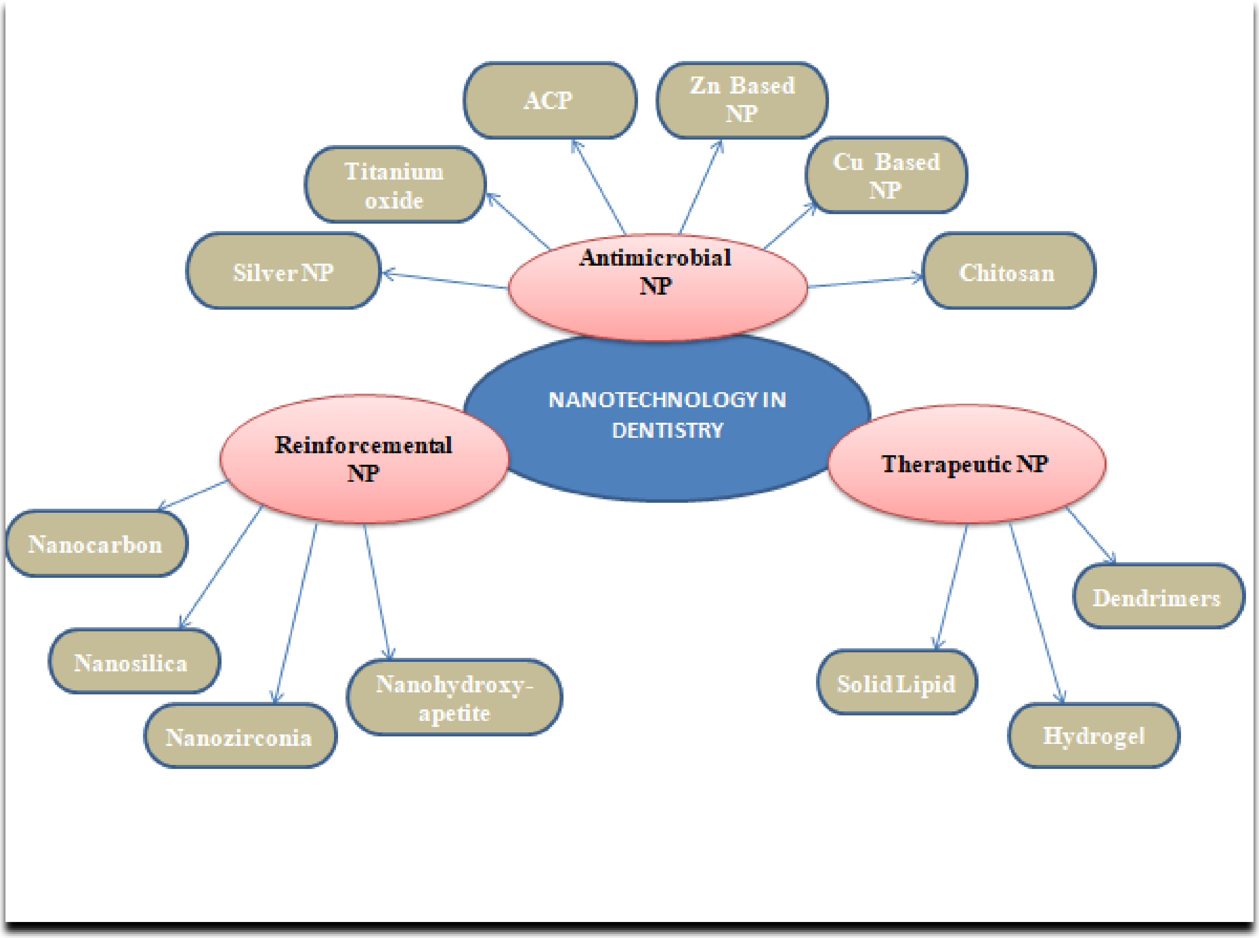

Figure 1: Dental Applications of Nanoparticles (Priyadarsini et al., 2017)

SILVER NANOPARTICLES

Silver nanoparticles (AgNPs) are used in many commercial applications to prevent microbiological growth. Because silver nanoparticles are becoming more and more used in modern materials, they will unavoidably end up in environmental systems. The natural microbial equilibrium that exists in these habitats may be significantly jeopardized by the same mechanism of action that makes them appealing as an antibacterial tool. Most studies on the potential environmental hazards of silver nanoparticles have focused on particular issues, such as the effects of the particles on plants, earthworms, and rivers and estuaries. Research has to focus on all facets of the microbial world, highlighting potential risks and finding answers to problems before they become significant. By concentrating on the antibacterial uses, toxicological processes, and environmental effects (mostly on soil) of silver nanoparticles, this assessment draws attention to the knowledge gaps that currently exist. (Zhang et al.,2016)

Green produced AgNPs are being used more and more to treat and prevent dental conditions. Because of their alleged biocompatibility and broad-spectrum antibacterial activity, green produced AgNPs have been used into dentifrices to decrease pathogenic oral microorganisms. In the current investigation, Gum Arabic AgNPs (GA-AgNPs) were combined with a commercial toothpaste (TP) at a non-active concentration to create GA-AgNPs - TP. Agar disc diffusion and microdilution assays were used to assess the antibacterial activity of four commercial TPs, 1-4, on a subset of oral microorganisms. Based on the results, the TP was chosen. Following the formulation of GA-AgNPs - TP-1 using the less active TP-1, the antibacterial activity of GA-AgNPs (0.4g) was compared to GA-AgNPs - TP- 1. By utilizing the MTT test, the cytotoxicity of GA-AgNPs (0.4g) and GA-AgNPs - TP-1 was also evaluated on buccal mucosa fibroblast (BMF) cells. It was shown in the study that the antibacterial activity of GA-AgNPs (0.4g) was maintained when it was mixed with a sub-lethal or inactive concentration of TP-1. GA-AgNPs (0.4g) and GA-AgNPs - TP-1 were shown to exhibit time- and concentration-dependent non-selective antibacterial activity and cytotoxicity. After exposure for less than an hour, these actions were immediate, limiting the proliferation of bacteria and BMF cells. Still, dentifrice is typically used for two minutes and then rinsed off, so there's no risk of damaging the oral mucosa. Though there is potential for GA-AgNPs - TP-1 as a TP or oral healthcare product, further research is needed to enhance this formulation's biocompatibility (Ahmed et al.,2023).

HYDROXYLAPATITE

In tissue engineering, orthopedics, and dentistry, hydroxylapatite (also known as hydroxyapatite, HAp) is a great option due to its exceptional biocompatibility with a wide variety of cells and tissues. The high surface-to-volume ratios of nanoscale materials allow for better performance than that of traditional materials. In addition to its recent uses in the realms of dentistry and medicine, this study highlights current understanding and recent advancements in the fabrication processes of nanosized (or nanostructured) HAp particles (Okada et al., 2012)

Ten toothpaste slurry samples with 10 weight percent nano-HAp, 10 toothpaste slurry samples with 1 weight percent nano-HAp, 10 toothpaste slurry samples without nano-HAp as a negative control, and 10 toothpaste samples with water as a blank control were randomly assigned to the four groups. An electric toothbrush from IO, Oral B, Germany was used for manual brushing. A brushing cycle of sixty cycles per minute was being performed. The 30 second tooth brushing period corresponded to 30 times the brush head's full back-and-forth or circular movement in 30 seconds. A controllable range of 0.8 to 2.5 N was used for brushing force. The brushing angulation was 90°. A combination of vertical and rotational movement with a back-and-force length of 2.5 cm was applied.

The samples were brushed, then gently rinsed with distilled water and kept for 24 hours at 37 °C in artificial saliva before being applied again. Three applications of the nano-HAp—designated as HAp 1, HAp 2, and HAp 3—were made to the tooth surfaces. (Shang et al., 2022)

GOLD NANOPARTICLES

Gold nanoparticles (AuNPs) have several surface functions and special qualities, they have been used extensively in bionanotechnology. An adaptable platform for nanobiological assemblies containing oligonucleotides, proteins, and antibodies is made possible by the simplicity of AuNP functionalization. AuNP bioconjugates have emerged as intriguing options for the development of innovative biomaterials intended for biological system research (Yeh et al.,2012).

Caries is a type of injury to teeth that is brought on by the degradation of the enamel by acidogenic organisms such as lactobacillus and *Streptococcus mutans (S. mutans).* It is brought on by eating a diet high in carbohydrates or by salivary dysfunction . Because of their nanosize, gold nanoparticles (GNPs) have a greater surface area and can interact with both organic and inorganic molecules more. As a result, GNPs are one of the possible anti-terrorist agents . The bacteriostatic and bactericidal properties of GNPs, AgNPs, and zinc oxide nanoparticles (ZnPs) against *S. mutans* were compared by Hernández-Sierra et al. (2008). AgNPs (0.0976 to 100 μg/mL), GNPs (0.192 to 197 μg/mL), and ZnPs (3.90 to 4000 μg/mL) were the varied amounts that the researchers worked with. The minimal inhibitory concentration (MIC) was determined using a method called liquid microdilution. At lower concentrations, AgNPs were found to have superior antibacterial activity when compared to GNPs and ZnPs. In order to study the impact on *S. mutans* at low temperatures in plasma, Park et al. (2014) employed GNPs (30 nm). GNPs alone were contrasted with the effect. Two methods were used to quantify the survival rate: bacterial viability stains and colony-forming unit counts (CFU). According to the study's findings, introducing GNPs enhanced *S. mutans'* ability to destroy low-temperature bacteria. This could be because GNPs increase the energy in the plasma, stressing the *S. mutans* cell walls. The antibacterial activity of Chlorhexidine gluconate-CHX (0.2%) and NanoCare (GNPs and AgNPs) against *S. mutans* was compared by Gamily et al. in 2018. When NanoCare and CHX disinfection were used against Gram-positive cariogenic bacteria (*S. mutans*), their antibacterial efficacy shown a considerable reduction in the number of bacteria in each case. However, CHX demonstrated a significantly greater rate of bacterial inhibition. This could be as a result of NanoCare's gold ions, which are released from GNPs and may lessen the disinfectant's antibacterial effectiveness. It did, however, demonstrate that, in comparison to conventional agents, the creative addition of GNPs to the cavity disinfectant can enhance the material's antibacterial activity and reduce the incidence of secondary caries.(Bapat et al.,2020)

CALCIUM NANOPARTICLES

Chemically inert materials are those that contain micro- and nanoparticles of calcium carbonate. As such, they are extensively studied in the areas of drug delivery, biosensing, and filler material for the adhesive, plastic, paper, paint, and sealant industries. An excellent option for both industrial and biomedical applications, calcium carbonate-based nanomaterials have unique qualities like biocompatibility, a high surface-to-volume ratio, robustness, ease of synthesis and surface functionalization, and the capacity to exist in a range of morphologies and polymorphs. Developing new synthesis techniques for calcium carbonate particles of micrometer and nanoscale diameters has attracted a lot of research attention (Fadia et al.,2021).

Toothpastes containing calcium orthophosphates were reported to reduce dental sensitivity and to encourage a partial remineralization of the demineralized enamel . Depending on the addition of other ingredients, these toothpastes may also have some whitening impact . For instance, a combined study looked into the whitening and polishing capabilities of toothpastes containing hydoxyapatite (HA). The brightening and whitening qualities were tested on volunteers using two colorimeters with two specifically designed fiberscopes, while the polishing properties were assessed using simulated teeth polished with various toothpastes. The findings showed that while adding HA to the toothpaste increased teeth whitening significantly, it had no effect on the toothpaste's polishing abilities. Additionally, it was discovered that the whitening and brightening qualities rose in tandem with the toothpaste's HA content.

However, toothpaste containing HA seems to be successful in lightening teeth, and this effect was not brought about by polishing the surface of the teeth. Other researches have also discovered that toothpastes containing HA have whitening benefits (Dorozhkin, 2019)

ZINC NANOPARTICLE

Zinc (Zn) and its oxide (ZnO) are among the most intriguing and promising metallic nanomaterials. In addition to being a vigorous reducing agent and a reasonably active element, zinc has the ability to readily oxidize and create zinc oxide, which is useful for the creation of zinc oxide nanoparticles (ZnO NPs) (Bielański., 1997). As one of the most significant microelements, zinc is critical to human organisms. It is intracellular and mostly found in the nucleus, cytoplasm, and cell membrane of all bodily tissues, including muscle and bone (which contain 85% of the total zinc content in the body), skin (11%), and all other tissues. Zinc plays both structural and catalytic roles—it is an active core of many macromolecules and enzymes—and has been demonstrated to be essential for the correct operation of these entities. Protein subdomains can interact with DNA or other proteins thanks to the special scaffolding that zinc finger motifs offer. Additionally essential to metalloprotein function is zinc (Maret., 2011). While zinc is thought to be largely non-toxic due to its lack of redox activity, there is mounting evidence that free zinc ions may be responsible for several health problems, including the deterioration of neurons. Therefore, the manufacturing of zinc oxide nanoparticles and the binding of zinc cations with bioactive ligands (such as proteins) are carried out in order to reduce its harmful effect (Krol et al., 2017).

Zinc nanoparticle can be synthesized by physical, chemical and green methods. Massive amounts of nanoparticles can be created in a very short amount of time using a variety of physical and chemical processes. Solution-based methods, including as chemical precipitation, sol-gel, solvothermal, hydrothermal, and others, are among the most widely used techniques for producing ZnO NPs. They are also highly broad and straightforward. Chemical methods produce several toxic compounds that are surface-absorbing and have negative consequences when used in medicinal applications (Mirzaei et al., 2017). Plants, bacteria, fungi, algae, and other microorganisms can all be used in green synthesis (Figure 2). They enable the large-scale, impurity-free synthesis of ZnO NPs (Yuvakkumar et al., 2014). More catalytic activity is displayed by NPs made using a biomimetic technique, which also reduces the need for costly and hazardous chemicals. Certain phytochemicals secreted by these naturally occurring strains and plant extracts function as capping or stabilizing agents as well as reducing agents. For instance, the production of uniformly sized ZnO nanoflowers from *B. licheniformis's* cell soluble proteins demonstrated increased photocatalytic activity and photo stability (Auld.,2001). The manufacture of nanoparticles has also made use of plant components such as roots, leaves, stems, seeds, and fruits since their extract contains a wealth of phytochemicals that function as stabilizing and reducing agents (Agarwal et al., 2017).

Strong adsorption and high catalytic efficiency are two characteristics of ZnO nanostructures that make them increasingly popular in sunscreen production. Of all the metal oxide nanoparticles, ZnO nanoparticles are the most valuable because of their wide range of uses, which include drug administration, gas sensors, biosensors, cosmetics, storage, optical devices, window materials for displays, and solar cells (Huang et al., 2001). Because ZnO NPs modulate neuronal excitability or even release of neurotransmitters, they may have some involvement in the central nervous system and even in the development of illnesses. Studies have shown that ZnO NPs impact biocompatibility, neural tissue engineering, and the functioning of various cells or tissues; however, little is known about the impact on the central nervous system and disorders associated to it (Osmond et al., 2010). It has been suggested that ZnO NPs can alter synaptic transmission and influence spatial cognition capacity in vitro by increasing long-term potentiation (LTP) in rats. It's also likely that exposure to ZnO NP resulted in a genotoxic potential due to oxidative stress and lipid peroxidation. Nevertheless, due to their ability to target, ZnO nanoparticles may be helpful in the treatment of autoimmune diseases and/or cancer (Hanley et al., 2004).

Zinc Oxide Nanoparticles have a wide range of applications in the various branches of dentistry, such as in the field of restorative dentistry, endodontics, regenerative endodontics, periodontics, prosthodontics, orthodontics, oral medicine, cancer diagnosis, dental implantology, preventive dentistry and biomedical waste management. ZnO NPs have been found to improve the mechanical and anti-bacterial properties of dental restorative materials. When ZnO NPs were incorporated in dental resin composites, there was inhibition in the growth and adhesion of *S. mutans*, and in small amounts did not affect the mechanical properties. This is extremely beneficial in not only in the prevention of secondary caries but also in the interception of bulk fracture of the material (Pushpalatha et al., 2022). Zinc oxide nanoparticles have anti microbial activity against gram positive and gram negative bacteria and thus can be used in toothpaste and mouthwash. The anti-microbial activity of ZnO NPs depends on synthesis techniques, physico-chemical characteristics, evaluation tools, and techniques used to generate three-dimensional structures.

The anti-inflammatory activity of ZnO NPs in response to infections is another intriguing characteristic that helps combat gingivitis or caries. Zinc oxide nanoparticles (ZnO NPs) reduce inflammation in three ways: (i) by inhibiting the production of pro-inflammatory cytokines, such as IL-1β and IL-18, by blocking the action of necrosis factor kB and caspase 1 in activated mast cells and macrophages; (ii) by inhibiting the proliferation of mast cells by upregulating p53 and reducing the production of thymic stromal lymphopoietin linked to IL-13, a TH2 cytokine, along with IL-1 and tumor necrosis factor-α; and (iii) by suppressing the expression of cyclooxygenase-2 and inducible nitric oxide synthase in response to lipopolysaccharide. Due to their antibacterial properties, ZnO NPs can be found in mouthwash and toothpaste, which helps to combat gingivitis. It has also been shown that toothpaste containing ZnO improves the dentin of a tooth that has been extracted by lowering demineralization. Moreover, zinc has been added to bioactive glass toothpaste because of its antibacterial and anti-gingivitis properties. A higher zinc content in toothpaste may have superior antibacterial and anti-gingivitis properties (Carrouel et al., 2020).

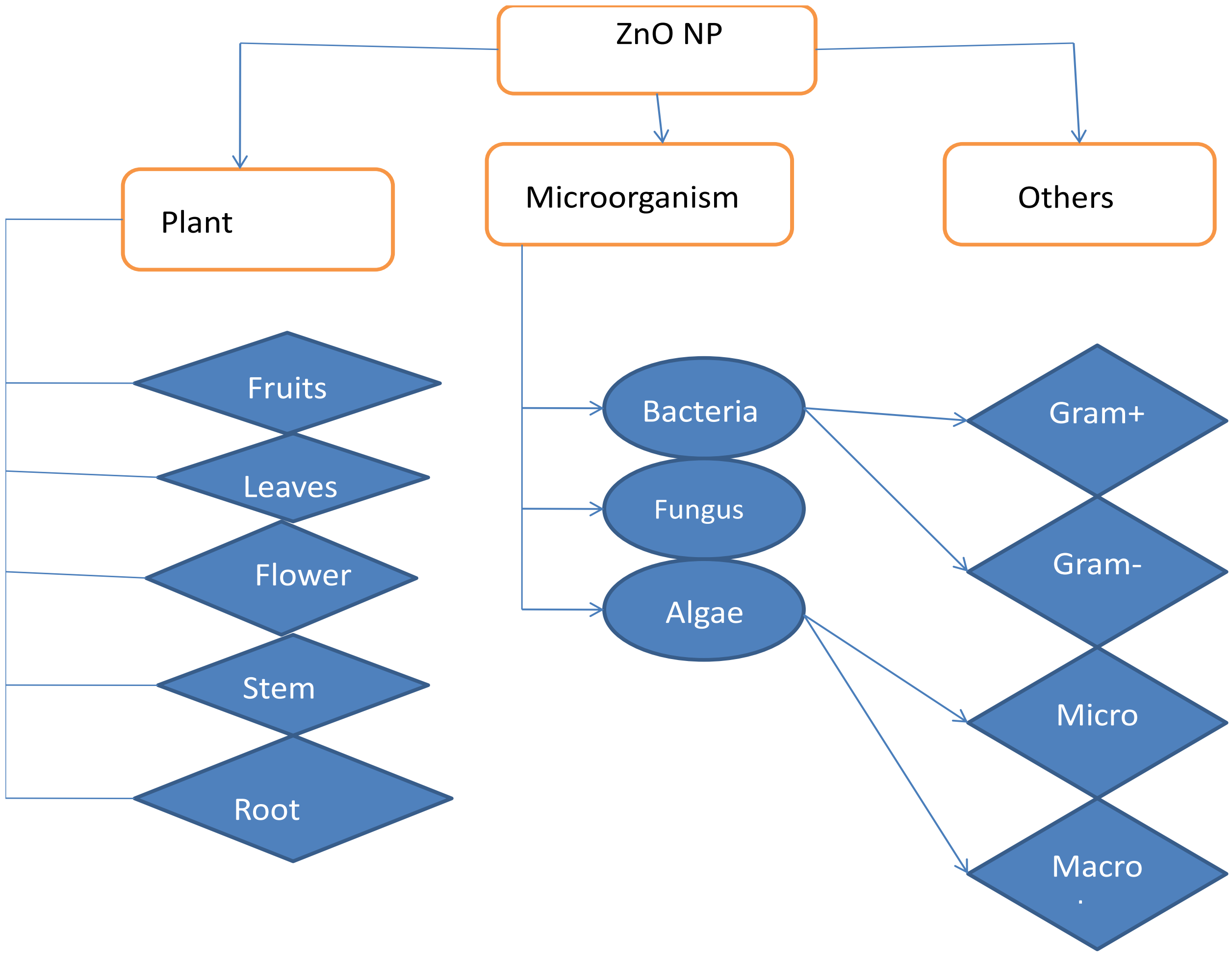

Figure 2: Zinc oxide Nanoparticle synthesis using various sources (Yuvakkumar et al., 2014)

SELENIUM NANOPARTICLE

Silver, gold, cerium, iron, selenium, silicon, titanium, and zinc metal nanoparticles have a distinctive place in the field of nanotechnology since they present a unique possibility as theranostic agents and have enormous potential as carriers for proteins, siRNA, chemotherapeutic drugs, etc. Selenium nanoparticles, or SeNPs, are among these NPs that have been investigated the most. Selenium (Se) is a colorless, non-toxic, physiologically inactive substance with a "zero" oxidation state. The regulation of sperm motility and immunomodulatory activity are two important functions of selenium proteins. The human genome has 25 selenoprotein genes. Selenoprotein P, thioredoxin reductase, glutathione peroxidase, and other antioxidant enzymes all contain selenium as selenocysteine. Se acts as the redox centre of all these enzymes and is essential for their biochemical activity. SeNPs have many therapeutic benefits, including anti-inflammatory, anti-tumor, antioxidant, and anti-diabetic effects. Its prooxidant characteristics in the cells cause the formation of reactive oxygen species (ROS), which damages the mitochondria and endoplasmic reticulum and degrades DNA. This is primarily responsible for the anticancer effect (Khurana et al., 2019). (Figure 3)

SeNPs have been synthesized using a number of techniques. These techniques fall into two main categories: chemical reduction and biological reduction. Biological reduction techniques involve the conversion of various organic and inorganic selenium compounds into non-toxic and advantageous selenium nanoparticles (SeNPs) by use of biological agents like bacteria or plant extracts. Chemical reducing agents are used in chemical reduction. Depending on the energy source or instrument utilized for the reaction, this approach might be further characterized. In this area, the majority of methods reported by researchers are hydrothermal, microwave, and sonochemical.

In the past 20 years, researchers have been more interested in the green synthesis of metal nanoparticles. SeNPs have a number of benefits over both organic and inorganic selenium compounds, but their low cellular uptake is the primary issue. For this reason, biological synthesis of SeNPs is preferred in order to provide better stability and biocompatibility. Biological agents derived from microbes and plant extracts are a better choice than chemical approaches for meeting the growing need for non-hazardous, low-cost preparation techniques. Biological extracts have been shown to function as stabilizers for nanoparticles and as bio-reducing agents. These biological reagents consist of plant extracts, bacteria, fungi, algae, and protein molecules. Employing plant extracts is much more economical than employing fungi or bacteria because bacterial separation and culture demand for specialized knowledge, skills, and equipment. This process can create high-quality SeNPs with little to no product waste, without the need for specialized equipment, and without a lot of solvent. As a result, these techniques are seen as simple, affordable, and environmentally beneficial (Bisht et al., 2022).

One of the materials that has been widely studied and applied in endodontic surgery is mineral trioxide aggregate (MTA). On the other hand, MTA has some disadvantages as a long-time setting and lack of plasticity. Thus, some investigators have studied the admixing of nanoparticles to MTA in order to generate a material with new properties that could overcome these drawbacks. Selenium (Se) nanoparticles (SeNPs) have become increasingly popular, given their unique properties, and have also been used in dentistry and other sectors. SeNPs possess excellent antioxidant properties and biocompatibility, which might be beneficial for tissue regeneration and healing process. SeNPs could also be used for dental applications because it demonstrates antibacterial effects against both planktonic cells and biofilms of oral pathogens as well (Shehab et al., 2024).

There are numerous uses for SeNPs in the preservation of dental tissues and the prevention of caries. Selenium nanoparticles added to mouthwashes, chewing gum, and toothpaste may be able to restrain the growth of bacteria that cause cavities. To avoid secondary dental caries, selenium nanoparticles can also be added to restorative cement, pit and fissure sealants, endodontic sealers, and luting cement. Our understanding of the therapeutic efficacy of selenium nanoparticles in the prevention of dental caries can be enhanced by more in-depth research in these areas (Dhanraj et al., 2021).

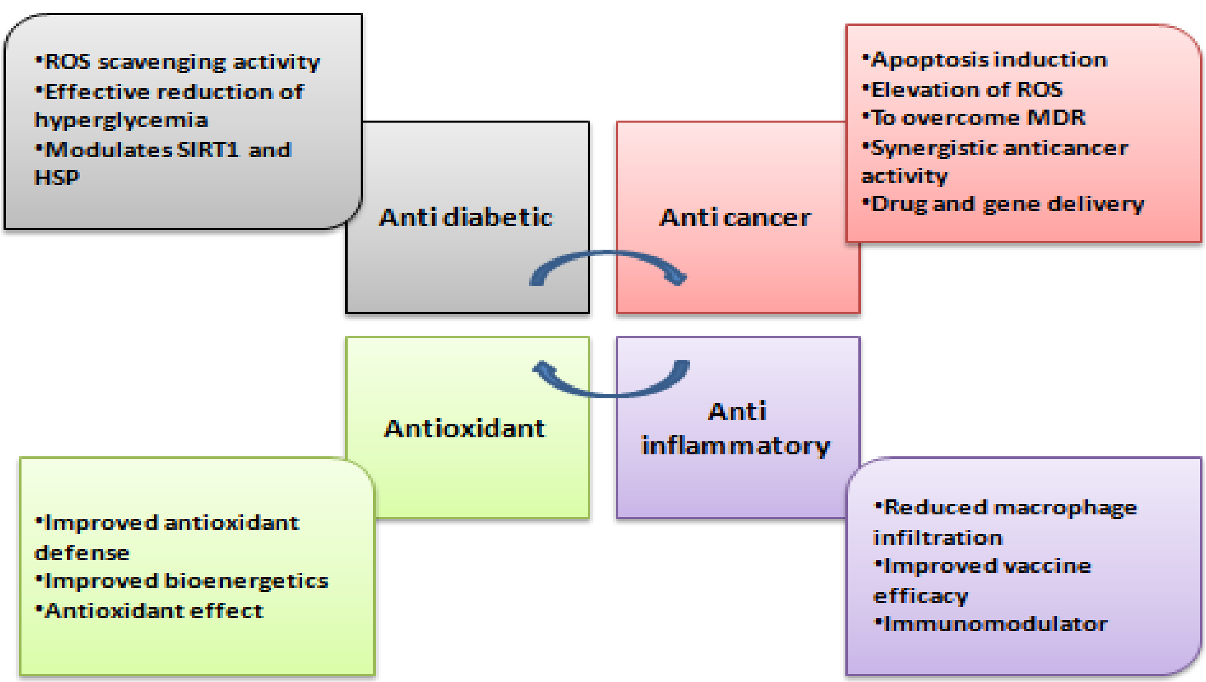

Figure 3: Therapeutic applications of Selenium Nanoparticles (Khurana et al., 2019).

FUTURE ASPECTS

The study of and advancement of minute components of materials, such as atoms or molecules, is the main goal of the scientific discipline of nanotechnology. This has significant effects on many other sectors, including studying medications, diagnosing ailments, and strengthening our immune systems. The area of dentistry has seen a new development known as nanodentistry, thanks to numerous applications of nanotechnology. Dental procedures have significantly improved and now provide a wider choice of possibilities because to substantial research in biomaterials and nanotechnology. Nanomaterials have distinctive properties that are absent from more expansive materials. There are many advantages to nanodentistry over conventional solutions. It can boost hypersensitive capacity, whitening, remineralization, bacterial eradication, biofilm removal, enhanced fillings, and cavity sealing. Despite the aforementioned difficulties, researchers are currently working hard to find less expensive techniques to produce NPs. Although NPs have a lot of potential, using them can have certain drawbacks. The issues with using nanoparticles are related to their decreased stability, propensity to aggregate, and potential for releasing metal ions or altering their composition through surface oxidation. Regarding NPs, the level of cytotoxicity could rely on the kind of nanoparticles (NPs), their size, stability, shape, functionalization, chemical purity, and agglomeration susceptibility, among other factors. Research has shown that a variety of tactics, including altering the NPs' size, shape, and charge as well as modifying them with ligands and coatings containing additional biocompatible chemicals, might lessen their toxicity. The effects of NPs on organisms after prolonged use are one reason why it is still important to continue research their biological compatibility. Understanding how NPs interact in biological systems is crucial to ensuring the safe use of these materials for medical applications and their potential communication with living organisms. In compliance with the requirements and to support the development of NPs for dental care products, numerous novel and innovative items have been investigated and may find application in the business world. Positive results from these materials' performance during testing were obtained. Its exceptional benefit, capacity, and chemical makeup make it an extremely good choice for an active ingredient in toothpaste intended for dental care (Abedi et al., 2024).

CONCLUSION

The area of preventive dentistry, nanotechnology has significantly changed practice and at the moment, a wide range of oral prophylactic activities incorporate these advancements. These days, mouthwash and toothpastes are made with NPs that have anti-microbial, anti-inflammatory, and remineralizing qualities. Nanomaterials have a wide range of potential applications and views that enable them to be successful due to their promising outcomes and diversified, frequently unpublished features. However, NPs' benefits—small size, surface characteristics, quantum state, migration, aggregation, mutation, and generation of free radicals—also make them hazardous. Because of the nearly infinite applications for NPs, research into them is currently one of the most explored areas of science. As a result, safety and regulatory issues need to be considered and raised, particularly with regard to the use of hydroxyapatite NPs in dental care products.

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