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A review on acceptability of denture polymers having gold and silver nanoparticles

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Abstract

In dentistry, polymethyl methacrylate (PMMA) is commonly used as a base material for dentures. PMMA has been widely used in a range of dental applications because of its specific features, including its low density, aesthetics, cost-effectiveness, ease of manipulation, and flexible physical and mechanical characteristics. Despite having many advantageous qualities, it has a lot of cons like weak flexural strength, poor wear resistance, polymerization shrinkage, and poor durability etc., The emergence of nanotechnology has allowed for the improvement of the afore-mentioned drawbacks through the use of different nanoparticles. Silver nanoparticles have been used in dentistry due to their antimicrobial, and antifungal properties. They also enhance the mechanical properties of materials leading to improved outcomes. Gold nanoparticles are available in different sizes and concentrations to exhibit their beneficial outcomes. This review aimed to discuss the properties of silver and gold nanoparticles, their form of incorporation, benefits, acceptance and their clinical significance when added with denture polymers.

Keywords: Denture polymers, Properties of nanoparticles, Gold nanoparticles, Silver nanoparticles.

1. Introduction

In our daily life, nanotechnology is employed extensively, especially in the field of medicine. Nanoparticles (NPs) are discrete clusters of atoms with a plethora of medicinal uses, including tissue engineering, drug delivery, antimicrobial agents, regenerative medicine, and cancer treatment [1]. Nanotechnology and smart nanomaterials such as nanoclays, nanofibers, nanocomposites, metallic nanoparticles, nanospheres and nanocrystals are increasingly being used in dental applications [2]. Polymethyl methacrylate (PMMA) is widely used as denture base material in dentistry. Due to its distinctive qualities, including its low density, aesthetics, cost efficiency, simplicity of manipulation, and adaptable physical and mechanical characteristics, PMMA has been popular for use in a variety of dental applications [3]. Although it has numerous favourable properties it has several drawbacks like as poor durability, polymerization shrinkage, poor wear resistance, poor flexural strength etc., affecting the dimensional stability and aesthetics of the denture [4]. A variety of modifications have been introduced to overcome the drawbacks of conventionally used denture polymers. Incorporating silver and gold nanoparticles is one such approach to improve the characteristics of traditional denture polymers. This review was focused on explaining briefly the incorporation of nanoparticles into denture polymers, the physical, biological and chemical properties of silver and gold nanoparticles followed by their drawbacks.

2. What are Nanoparticles?

Materials having overall dimensions in the nanoscale (under 100 nm) are known as nanoparticles [5]. A nanoparticle is defined as "a particle of any shape with dimensions in the 1×10^{-9} and 1×10^{-7} m range", according to IUPAC (International Union of Pure and Applied Chemistry) [6]. Numerous cosmological, geological, climatic, and biological phenomena all naturally synthesize nanoparticles [7,8]. Despite being unaware of its nature, artisans, glassmakers and potters have been using nanoparticles since prehistory. In his classic 1857 study, Michael Faraday became the first scientist to describe the optical characteristics of nanometer-scale metals [9]. Researchers adopted the name "ultrafine particles" in the 1970s and 1980s, when the first comprehensive basic investigations using nanoparticles were being conducted in the United States (by Granqvist and Buhrman) [10] and Japan (inside an ERATO Project) [11]. However, the word "nanoparticle" gained popularity throughout the 1990s, prior to the United States National Nanotechnology Initiative [12].

The physical and chemical characteristics of nanoparticles might differ dramatically from those of their bigger material counterparts. Non-spherical nanoparticles, such as prisms, cubes, and rods, have chemical and physical characteristics that rely on their form and size (anisotropy). Due to their intriguing optical characteristics, non-spherical nanoparticles of gold (Au), silver (Ag), and platinum (Pt) are finding use in a variety of fields [13].

2.1 Silver nanoparticles (AgNPs)

Silver nanoparticles are tiny particles composed of silver with a size between one nanometer to one hundred nanometers [14]. Although diamond, octagonal, and thin sheets are also frequent, spherical AgNPs are the most widely utilised [14]. Due to the high surface-to-volume ratio, nanosized metallic particles are distinctive and can significantly alter physical, chemical, and biological characteristics [15]. Diverse synthesis techniques have been used to meet the need for silver nanoparticles. Wet chemistry, or the nucleation of particles in a solution, is the domain in which nanoparticle production is most frequently carried out. Other methods include citrate reduction, through monosaccharides, reduction via sodium borohydride, polyol process, ion implantation, silver mirror reaction etc., [16]. Precise particle characterisation is required following synthesis since a particle's physicochemical characteristics may have a big influence on those particles' biological characteristics [17]. The manufactured nanoparticles must be characterised before use to address the problem of safety and utilise the full potential of any nanomaterial for human welfare, in nanomedicines, in the healthcare sector, etc. [18]. A number of analytical methods are used for the characterization of the material, such as UV-vis spectroscopy, X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and atomic force microscopy (AFM) (Fig.2) [17]. AgNPs, among other metallic nanoparticles, has drawn particular attention in scientific studies because they exhibit antibacterial qualities and biological activity against bacteria, fungus, and enveloped viruses [19]. Since some researchers have embraced the method of including antimicrobial chemicals in dental biomaterials, AgNPs have therefore emerged as a potential substance to be employed in dentistry [20].

2.2 Gold nanoparticles (AuNPs)

Gold nanoparticles are small gold particles with a diameter of 1 to 100 nm which, once dispersed in water, are also known as colloidal gold [21]. Chinese, Arab, and Indian scientists who were able to acquire colloidal gold as early as the fifth and fourth centuries BC left behind treatises that include the first information on the substance [22]. Despite having a long history, the "revolution in immunochemistry" related to the use of gold nanoparticles (GNP) in biological investigations was only initiated in 1971 by the British researchers Faulk and Taylor [23]. Typically, chloroauric acid ($H[AuCl_4]$) is reduced to make AuNPs in a liquid (referred to as "liquid chemical techniques") [24]. Various methods which have been proposed for the synthesis of gold nanoparticles include the Turkevich method [25], Perrault method [26], Brust-Schiffrin method [27], Martin method [28], Navarro *et al.* method [29], Block copolymer-mediated method [30] and by sonolysis [31]. The use of AuNPs in contemporary biology and medical research is extremely diverse. It is used widely due to their distinctive physical and chemical characteristics AuNPs have been tested in the treatment of gum disorders, dental caries, tissue engineering, dental implantology, and cancer diagnostics due to their nanostructures, high surface volume, and biocompatibility [32].

3. Properties of silver nanoparticles (AgNPs)

AgNPs' physical and chemical characteristics, including their surface chemistry, shape, size & distribution, composition, particle reactivity, dissolution rate, coating/capping agglomeration and process of synthesis are key components in determining their cytotoxicity [17].

3.1 Physical properties

The physical properties of AgNPs include their size, shape, particle composition, hardness, tensile strength, flexural strength and elastic modulus [33]. AgNPs are approximately between 1 nm and 100 nm in size. They are spherical-shaped with a smoother surface and are well dispersed in the matrix. The average diameter is found to be approximately 35 nm. They have narrow size distribution. These are highly crystallized particles due to their uniform lattice framework [34]. It is majorly composed of silver oxide due to its higher surface area, and materials used in the synthesis include citrate, boro hydrate and thio glycerol [33]. According to a nanoindentation study of AgNPs by Dhriti Ranjan Saha *et al.*, the modulus and hardness value showed 103.93 and 3.12 GPa [35]. The tensile strength of AgNPs is 87.32 MPa under 350 K temperature [36]. The mechanical properties of the conventional PMMA denture base material and AgNPs modified denture base materials are given in Table 1.

3.2 Optical properties

The optical properties of AgNPs are highly based upon their particle size as it directly affects the absorption and scattering properties. The process includes exposing the AgNPs to a specific wavelength which induces the oscillation of the electrons leading to charge separation [37]. These form the SRP band (Surface Plasmon Resonance). The position of the maximum, the shape and the intensity of AgNPs' absorption band depend on their size, shape and properties of the surrounding liquid medium [38]. The smaller the particle size, the shorter the wavelength and weaker absorption spectra [37].

Table 1. Properties of conventional PMMA and AgNPs modified PMMA.

Properties	PMMA	PMMA + AgNPs
Young's Modulus	2.9 GPa	Increased
Tensile strength	70 MPa	Decreased
Flexural strength	2.9 MPa	Increased
Elastic modulus	2.9 GPa	Decreased
Vicker's hardness	17.57 Kg/mm^2	Increased

3.3 Chemical properties

Chemical properties include agglomeration, dissolution rate, particle reactivity, the efficiency of ion release and reducing agents used in the synthesis [33]. Agglomeration is a process that causes a decrease in surface free energy by an increase in size and a decrease in surface area. It is caused due to adhesion of particles by weak forces [39]. It is characterized using TEM analysis. According to this analysis, when more than 500 nanoparticles were agglomerated majority of the smaller particles were in the range of 2-10 nm and larger particles were approximately 15-30 nm in size. These smaller agglomerates were formed with a diameter of 10-40 nm [40].

The dissolution rate is the rate at which the particles dissolve in a medium [41]. The dissolution rate of AgNPs is highly dependent on their size. Particles with sizes ranging from 5 nm dissolved in acidic concentrations ten times weaker than the heavier particles [40]. The reactivity rate of AgNPs to acidic media is shown to be extremely high compared to other substrate media [42]. The efficiency of ion release mainly depends upon the shape, amount, and distribution of the nanoparticles. The technique used for measuring the ion release is Inductively Coupled Plasma Optical Emission Spectrometry [43]. The reducing agents used for the reduction of silver ions in an aqueous medium are sodium citrate, ascorbate, sodium boro hydrate, elementary hydrogen, polyol process, tollens reagent, dimethyl formaldehyde and poly block copolymers. These agents reduce the silver ions and lead to the formation of metallic silver [44].

3.4 Biological properties

The biological properties of AgNPs are distinctive from those presented by traditional bulk materials because of their small particle size and other mechanical features. These biological properties broadly include Antimicrobial and Antifungal properties [44]. The smaller particle size and large surface area of AgNPs provide potent antibacterial effects at a low filler level, diminishing the AgNPs concentration necessary for its efficacy and avoiding negative influence on mechanical properties. Also, they penetrate through cell membranes more readily, resulting in higher antimicrobial activity, which is especially important since microorganisms in biofilms are more resistant to antimicrobial agents [45].

Silver has strong antifungal effects in various biomedical applications. The antifungal properties are due to their release of small amounts of different incorporated substances into the physiological environment. Their antifungal effects may also be related to a wide spectrum of cytotoxic effects [46].

4. Properties of Gold nanoparticles

Spherical AuNPs (Figure 1) have advantageous characteristics such huge surface-to-volume ratios, excellent biocompatibility, and low toxicity. They also have size- and shape-related optoelectronic features [47].

4.1 Optical properties

Depending on particle size, shape, local refractive index, and aggregation state, AuNPs absorb and scatter light, producing colours ranging from vivid reds (smaller particles) to blues to black to eventually clear and colourless (larger particles). Conduction electrons on the surface of the nanoparticle vibrate in resonance with incoming light, a process known as localised surface plasmon resonance (LSPR) that causes these hues [49]. The ability to quench fluorescence and surface plasmon resonance (SPR) are two crucial characteristics of AuNPs. As the size of the core rises from 1 to 100 nm, spherical AuNPs display a variety of hues (such as brown, orange, red, and purple) in aqueous solution and often exhibit a size-relative absorption peak from 500 to 550 nm [50]. As mentioned earlier, optical properties of AuNPs also depeneded on the refractive index near the nanoparticle surface. The nanoparticle extinction spectrum moves to longer wavelengths as the refractive index increases close to the nanoparticle surface (known as red shifting) [51].

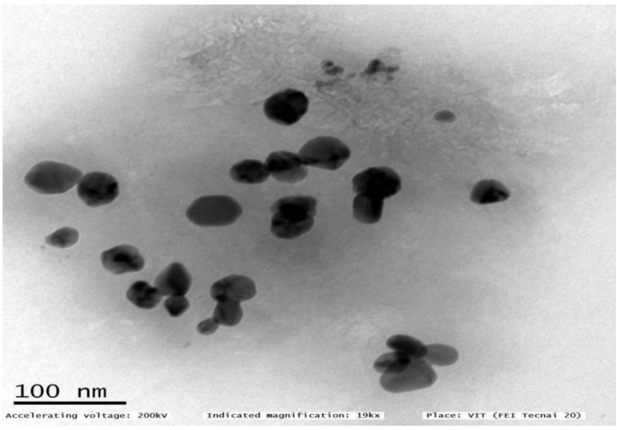

Figure 1. Tramission electron microscopic image of spherical AuNPs [48]

4.2 Biological properties

The size and form of AuNPs affect their resistance to fungus. AuNPs prevent Candida species from using their H^+-ATPase or blocking transmembrane H^+ efflux. The size and form of AuNPs have an impact on their antifungal action. The greater surface area of AuNPs limits transmembrane H^+ efflux, which has an antifungal effect or stops Candida species from acting as an H+-ATPase. AuNPs' antibacterial effect is less potent than that of silver nanoparticles (AgNPs) [52-54]. AuNPs' ability to inhibit ribosomal subunits for t-RNA binding, which leads to the breakdown of biological processes, is what gives them their antibacterial properties. In addition, it alters the membrane potential and prevents ATP synthase from working properly, which lowers ATP levels and weakens metabolism. AuNPs have less harmful effects on mammalian cells because their action is not dependent on Reactive Oxygen Species (ROS) [55].

4.3 Chemical properties

AuNPs have the advantage over many other nanoparticles in that they can create strong chemical interactions with groups that contain S and N [56]. Because of this ability, AuNPs are capable of getting attached to a range of polymers or organic ligands, having an impact on their biocompatibility [57]. Haruta *et al.* discovered in 1987 that AuNPs have outstanding efficiency in catalysing the oxidation of CO at or even below room temperature, and based on this research into AuNP-based bio-mimetic catalysts [58,59].

A variety of materials can be used to functionalize gold nanoparticles. As capping agents, polymers like polyvinylpyrrolidone (PVP) and tannic acid are frequently utilised to stabilise gold nanoparticles [60]. By using thiol-gold bonds, which are incredibly stable, or by using physioadsorption, molecules can bind to a gold surface [60].

5. Incorporation of nanoparticles into denture polymer

The incorporation of Nanoparticles aims to decrease microbial colonization and increase oral health. Further addition of NPs also increases the flexural strength of the material. Nanoparticle-induced resins have been satisfactorily used as denture bases and tissue conditioners [61].

5.1 Forms of incorporation

AgNPs were incorporated into the resin by different methods. But the most common method is adding it in concentrations of 0.05%, 0.5%, and 5% of AgNPs, by mass [62]. The mechanical properties of this modified resin include increased flexural strength. Acosta-Torres *et al.* [63] prepared a PMMA that contains 1 ųg/mL of AgNPs. Increasing nanoparticle concentration, these are more effective and work better. The synthesized Ag and Au Nanoparticles are collected in 0.1 wt% of polyvinylpyrrolidone (PVP) as it prevents agglomeration. This concentrated compound is filtered through centrifugal filter membranes so that the PVP stabilizer is removed [64]. The filtered solution is used to prepare the nanocomposite. A conventional heat polymerized PMMA is used as a matrix component, and the nanoparticles are the reinforcing component. Optimal concentrations such as 0.05%, 0.5% and 5% of nanoparticles are used to obtain the desired characteristics. To prevent agglomeration, the nanoparticles are first dispersed in the liquid MMA at the above-described concentrations and then mixed with PMMA powder. This procedure has to be done according to the manufacturer‘s instructions [65].

6. Clinical significance

The characteristics of denture resins have been substantially enhanced by the use of nanoparticles [66,67]. A PMMA denture base augmented with various nanoparticles served as a demonstration of the outstanding qualities the resulting nanocomposite goods exhibit compared to pure materials [68]. The integration of AgNPs in denture-base acrylic resins has been the subject of numerous papers in the literature [63, 69-73].

Hamedi-Rad F *et al.* studied the effect of nanosilver addition on the mechanical and thermal characteristics of the acrylic base of complete dentures. They reported that 5.0 weight percent of nanosilver was added to reduce any potential unfavourable changes in the mechanical chemical properties of the acrylic base of the denture [70]. According to the research by Sodagar *et al.* (2012) [71], the addition of 0.05% AgNPs decreased one brand of self-curing resin's flexural strength while increasing the strength of the other brand. Accordingly, it is stated that the key elements influencing the flexural strength of PMMA are the type of acrylic resin and the quantity of NPs contained therein. On the contrary, Alla RK *et al*. reported that the addition of AgNPs decreased the flexural strength [72] and increased the surface hardness [73]. In contrast, Kassaee *et al.* (2008) [72] observed an increase in the flexural strength and antibacterial activity of the self-cure acrylic resin incorporated with 0.5 wt%. Chladek *et al.* (2013) [73] reported that the mechanical and physical properties of the final polymer are adversely affected by increasing AgNP concentration. A few Opportunistic oral pathogens such as streptococcus mutans, colonize the acrylic materials causing several dental infections; denture stomatitis. In these cases, AgNPs can be added to the acrylic resin to retard the growth of such bacteria hence acting as a strong antibacterial agent [76.77]. According to the research done by Nam KY *et al.* [78], Ag-denture acrylic may function as a low-releasing antifungal device, which may aid elderly people who wear dentures and have poor hand dexterity or cognitive impairments in maintaining better oral hygiene.

Although there is numerous research in the literature that examines the antibacterial efficacy of AuNPs' solutions against various pathogens, there is a shortage of data on how these AuNPs interact with denture base polymer [79,80]. According to a study by Tijana A. *et al.* [81], the addition of AuNPs considerably enhanced the thermal conductivity of PMMA. By gradually increasing the volume fraction of the AuNPs, PMMA/Gold nanocomposites' thermal conductivity and microhardness by Vickers were both increased. Since the physic-mechanical properties are excellent, it would be advantageous if AuNPs were added to PMMA to increase its antibacterial activity [81]. It has also been confirmed that the addition of AuNPs had no significant impact on the mechanical characteristics of acrylic materials and had not resulted in any loss in flexural strength or elastic modulus below the usually recommended standards. The advantages of their antibacterial qualities, which will be further studied, should much outweigh the modest reduction in mechanical properties that was nevertheless required by the Standard requirements in this case [81].

7. Future research

Although adding AgNPs to acrylic resins has antibacterial benefits, its impact on the resin's mechanical characteristics needs to be investigated. The issue with the literature is similar in that AuNPs-doped denture base resins' antibacterial and mechanical capabilities have rarely been described simultaneously. For instance, there are no publications on the addition of gold in the internationally recognised literature, only papers on the addition of silver nanoparticles and a few other metallic nanoparticles. As a result, future research and attention must be focused on the aforementioned qualities.

8. Conclusion

Due to its inherent material qualities and strong biocompatibility, PMMA is now a suitable substance for the manufacturing of removable full and partial denture devices. It has been successfully reported in numerous research that adding silver and gold nanoparticles to denture resins has advantages. However, more research is needed to address the biocompatibility, and antibacterial concerns of these nanoparticles incorporated denture base materials.

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