PREPARATION AND CHARACTERIZATION OF POLY (METHYL METHACRYLATE)-SILVER NANOPARTICLES POLYMER COMPOSITE AS A DENTAL PROSTHESIS

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DEDICATION

This thesis is specially dedicated to my parents my father Abdelaziz, especially beloved mother Latra for her support, prayers. Encouragement and unconditional love may Almighty GOD.

To my beloved wife Malika, my kids Maram and Chouaib and Haroune and my siters Lemya, Loubna and Asma.

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ABSTRACT

Silver nanoparticles (AgNPs) have been used for centuries in the field of medicine due to the its antimicrobial properties. AgNPs had been synthesized and incorporated in different aspects of biomaterials. According to previous studies, AgNPs provides sufficient antimicrobial effect at lower filler level by increasing membrane permeability and destroying bacteria due to its small size. Therefore, AgNPs can be used in dentistry towards prevention and reduction of biofilm formation on the surfaces of dental prosthesis. The main objective of this study is to synthesize poly (methyl methacrylate)-silver nanoparticles antimicrobial acrylic resin for dental prosthesis. The antibacterial effect of the AgNPs incorporated into acrylic resin poly methyl methacrylate (PMMA) was studied and the incorporating effects on the thermal stability of these polymeric biocides were evaluated. Colloidal AgNPs were added to PMMA (ONDA-CRYL) with different concentration (0.021 mg/ml, 0.0525 mg/ml, 0.084 mg/ml). The antimicrobial activity of the silver nanoparticle incorporated into PMMA was measured using disk diffusion method. Thermal stability, morphological and average size, and size distribution of AgNPs/PMMA were determined by transmission electron microscope, scanning electron microscope, and X-ray diffraction. The thermal stability and the glass transition temperature of the four samples were determined by using the thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis. From this study, it was found that the modified PMMA prosthesis base containing 0.084 mg/ml of AgNPs (S3) significantly exhibited antimicrobial properties *in vitro*, where the number of biofilm bacteria formed is 1.10^4/ml comparing with the control sample (S0). The incorporation of AgNPs at concentration 0.084 mg/ml to PMMA shows thermal stability at temperature of 350^{o}C-370^{o}C without altering their mechanical properties. Therefore, the AgNPs-PMMA nanocomposite could be used as a dental prosthesis.

ABSTRAK

Nanopartikel perak (AgNPs) telah digunakan selama berabad-abad dalam bidang perubatan kerana sifat antimikrobnya. AgNPs telah disintesis dan digabungkan dalam pelbagai aspek biomaterial. Menurut kajian terdahulu, AgNPs memberikan kesan antimikrob yang mencukupi pada tahap pengisi yang lebih rendah dengan meningkatkan kebolehtelapan membran dan memusnahkan bakteria kerana saiznya yang kecil. Oleh itu, AgNPs boleh digunakan dalam pergigian ke arah pencegahan dan pengurangan pembentukan biofilm pada permukaan prostesis pergigian. Objektif utama kajian ini adalah untuk mensintesis poli (metil metakrilat)-perak nanopartikel resin akrilik antimikrob untuk prostesis pergigian. Kesan antibakteria AgNP yang digabungkan ke dalam resin akrilik poli metil metakrilat (PMMA) telah dikaji dan kesan penggabungan ke atas kestabilan terma biosida polimer ini telah dinilai. AgNP koloid telah ditambah kepada PMMA (ONDA-CRYL) dengan kepekatan deferen (0.021 mg/ml, 0.0525 mg/ml, 0.084 mg/ml). Aktiviti antimikrob nanopartikel perak yang dimasukkan ke dalam PMMA diukur menggunakan kaedah penyebaran cakera. Kestabilan terma, saiz morfologi dan purata, dan taburan saiz AgNPs/PMMA ditentukan oleh mikroskop elektron penghantaran, mikroskop elektron pengimbasan, dan pembelauan sinar-X. Kestabilan terma dan suhu peralihan kaca bagi empat sampel ditentukan dengan menggunakan analisis termogravimetrik (TGA) dan analisis kalorimetri pengimbasan pembezaan (DSC). Daripada kajian ini, didapati bahawa asas prostesis PMMA yang diubah suai yang mengandungi 0.084 mg/ml AgNPs (S3) secara signifikan menunjukkan sifat antimikrob secara in vitro, di mana bilangan bakteria biofilm yang terbentuk adalah 1.104/ml berbanding dengan sampel kawalan (S0). Penggabungan AgNPs pada kepekatan 0.084 mg/ml kepada PMMA menunjukkan kestabilan terma pada suhu 350^{o}C-370^{o}C tanpa mengubah sifat mekanikalnya. Oleh itu, nanokomposit AgNPs-PMMA boleh digunakan sebagai prostesis pergigian.

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LIST OF SYMBOLS AND ABBREVIATIONS

AgNPs -	Silver Nanoparticles
API -	Analytical Profile Index
ATP -	Lactate Deshydrogenase
CFU -	Colony Forming Unit
CVC -	Central Venous Catheters
DSC -	Differential Scanning Calorimetry
EFSA -	European Food Safety Authority
ETP -	Poly (Ethylene Terephthalate)
FDA -	Food and Drug Administration
LDH -	Lactate Deshydrogenase
MI -	Inverse Micelles
MIC -	Minimum Inhibitory Concentration
MBC-	Maximum Bactericidal Concentration
MMA-	Monomythacrylate (Monomer).
NCCIH-	The US National Center for Complementary and Integrative Health
ODCB -	Ortho-Dichlorobenzene
PMMA -	Poly Methyl Methacrylate Acrylic
PVP -	Polyvinylpyrrolidone
TEM -	Electronic Microscope with Transmission
TGA -	Thermogravimetric Analysis

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The protection and preservation of oral health is the major goal of dentistry against fungal and bacterial biofilms. Nanoparticle have become useful tools for various dental applications in endodontics, periodontics, restorative dentistry, orthodontics and oral cancers (Khurshid *et al.*,2015). Among them, silver nanoparticles (AgNPs) have been used in medicine and dentistry due to their antimicrobial activity and restorative properties of the oral mucosa (Abiodun *et al.*,2014). Biofilm is defined as an accumulation of microorganisms of different species adhering to a surface, usually related to an aqueous environment (Bonnaure *et al.*,2006).

The European Commission defines nanoparticles as small particles between 1 and 100 nanometers in size. Nanoparticles have different chemical properties from their larger counterparts due to the high surface-to-volume ratio and the possible occurrence of quantum effects at the nanoscale (Khurshid *et al.*,2015).

Nanomaterials have a larger surface area relative to their mass. The increment in the surface area generally means that the particle is more active (e.g., it increases biological activity relative to its mass compared to larger particles) (Bernhardt *et al.*,2010). Due to their nanoscale size, nanoparticles could interact more with the biological system, as they can easily penetrate cell membranes compared to silver particles or larger silver ions. It is assumed that the penetration of silver nanoparticles is highly dependent on the size and shape of the particles, as they can be in different shapes such as spheres, tubes or even cubes (Torres *et al.,* 2013). The interaction of AgNPs with microorganisms can be done in several way which may affect the growth. For example, AgNPs can release silver ions when they come into contact with bacterial cells. These ions can affect bacterial DNA replication functions, disable the production of certain cellular enzymes and proteins required for adenosine triphosphate (ATP) synthesis (Agnihotri *et al.,* 2014). In addition, silver ions can disrupt the respiratory chain by disrupting membrane-bound enzymes' function (Torres *et al.,* 2013). The smaller spherical AgNPs showed better inhibitory action (Reza et al., 2016). Thus, the amount of silver ions released from smaller particles inhibit more bacteria than silver ions released from larger particles (Farre *et al*.,2009; Simon-Deckers *et al.*, 2008).

Some work has shown electrostatic attraction between negatively charged microbial cells and positively charged AgNPs (Cao *et al.*,2001). Nanoparticulate systems have been proposed as the most suitable bactericidal agents (Matthew *et al.,* 2009). Due to electrostatic attractions and affinity towards Sulphur proteins, Ag^{+} ions adhere to the cytoplasm and cell wall and significantly increase permeability; this leads to the rupture of bacterial envelopes (Khorrami *et al*, 2018). As soon as the free Ag^{+} ions are taken up by the cells, the respiratory enzymes are deactivated, leading to the production of reactive oxygen species and the interruption of adenosine triphosphate release (Das *et al.*,2020; Katva *et al*.,2018).

Silver nanoparticles have been incorporated into biomaterials to prevent or reduce biofilm formation (Kalishwarala *et al.*,2010). It had been reported that silver nanoparticles have anti-bacterial activity against several types of bacteria including, Gram-positive bacteria such as Listeria, Gram-negative bacteria such as Salmonella, and even antibiotic-resistant bacteria, by disrupting cell wall and membrane, denaturing ribosomes, interrupting ATP production, and interfere with DNA replication (Silva *et al*.,2017). This is why AgNPs are very important in food packaging, the hospital environment, and anti-odour fabrics (Robert *et al.*,2016). Silver nanoparticles are also effective as antifungal, antiviral, and anti-inflammatory agents (Silva *et al.,* 2017).

AgNPs interact with the pathogenic virus in two main ways; AgNPs can either be binded to the virus's outer envelope, thereby inhibiting the attachment of the virus to cellular receptors, or binded to the DNA or RNA of the virus, which ultimately result in inhibiting replication or propagation of the virus within the host cell. (Salleh *et al.,* 2020; Wang *et al.,*2014). The anti-inflammatory effects of functionalized AgNPs were indicated by the decreased levels of pro-inflammatory cytokines in RAW264.7 cell line. In addition, pre-administration of AgNPs reduced oedema and cytokine levels in carragenana-challenged rat (David *et al.,*2014).

The synthetic resin used in dentistry are mostly Poly (Methyl Methacrylate) (PMMA) acrylic resin. To date, there are no other materials that have shown to match the appearance of oral soft tissue and have the same high fidelity as acrylic resins (Dong *et al.,*2016). Due to its satisfactory overall performance, it is widely used to construct complete dentures (Dong *et al.,*2016). However, many researchers have shown that PMMA can serve as a repository for many microorganisms and promote biofilm formation (Li *et al.,*2016). When various microorganisms colonize the denture, the insertion of the denture leads to a radical change in the oral environment. The underlying mucosa is isolated from the mechanical cleaning of the tongue and the free flow of saliva. The porous surface of PMMA and the irregularities of the anatomical surface of the denture also contribute to the accumulation of microorganisms. This is one of the main problems leading to stomatitis or candidiasis of the denture (Moura *et al.,* 2006). AgNPs in colloidal form have been used for over 150 years as a biocidal material in the USA since 1954 (Nowak *et al*.,2010). According to Wady *et al.* (2012) and Acosta-Torres *et al.,* (2012), the synthesis of PMMA containing 1 μg/ml of AgNPs demonstrated less *Candida Albicans* adhesion compared to pure PMMA, and this was observed by seeding or culturing *Candida Albicans* on the surface of acrylic resin discs containing silver nanoparticles. However, incorporating PMMA and AgNPs with dentures and studying its physical, thermal and anti-bacterial activities have not been studied.

1.2 Problem statement

The oral microbiome exists suspended in saliva as planktonic phase microorganisms or attached to denture surfaces as a plaque biofilm. Homeostasis of the plaque biofilm and its symbiotic relationship with the host is critical for oral health (eubiosis). Disequilibrium or dysbiosis within the plaque can be threatened by diet, smoking, poor hygiene, stress, leads to the proliferation of opportunistic bacteria, which can cause local infections (Morin *et al.*,2005). The introduction of removable prosthesis into the mouth several times a day, in the absence of appropriate hygiene, can constitute a microbial vector that disrupts the oral ecosystem leading to prosthetic stomatitis, cheilitis, and fibrous hyperplasia. The usage of PMMA in prosthesis manufacturing has a strong microbial adhesion due to its chemical composition and surface topography (roughness) and ultimately it increases the prevalence and progression of oral mucosal diseases.

Although the removable prosthesis is compatible with the oral environment, unfortunately, its removal can directly cause tissue aggression and trauma (inflammation, infection, ulceration and/or hyperplasia). The removable prosthesis can also indirectly be the reservoir and vector of endogenous or exogenous microorganisms. The establishment of hygiene rules is insufficient to ensure a balance in the oral ecosystem. With the advancement of science in terms of microbiological knowledge, dentists must not only consider the technical aspect of making this prosthesis, but must also take into account the physical, chemical and biological changes that it induces on the physiology of the oral cavity and its impact on the general health status (Barsotti *et al.*,2006)

The main objective of this research is to incorporate bactericidal and bacteriostatic substances such as silver nanoparticles in the colloidal form directly into the acrylic resin during prosthesis manufacturing. This would control sub-prosthetic bacterial growth (Craig *et al.*, 2003). The dental prosthesis tends to become a bioactive element, which can interact with the environment that contains it (Laurina *et al.*,2006). Poly (methyl methacrylate) (PMMA) acrylic resin are the most widely used as prosthetic base material for fabricating removable prosthesis, implant-supported prosthesis and intra-oral maxillofacial prosthesis.

Although PMMA resin has met all the requirements of an ideal denture base material, its susceptibility to microbial colonization in the oral environment is a major concern for clinicians. Many mechanisms, including the lack of ionic charge in methyl methacrylate resins, hydrophobic interactions, electrostatic interactions and mechanical attachment, contribute to biofilm formation (Laurina *et al.*,2006).

Local factors such as porosity, surface roughness, poor denture hygiene and continuous night-time denture wear can also contribute to colonization.

1.3 Research questions

Based on the problem statement, three research questions were posed, namely:

i). Will the AgNPs hinder the formation of biofilm on PMMA-AgNPs prosthetic surface?

ii). How will the silver nanoparticles be incorporated into the acrylic resin?

iii). Will the incorporation of silver nanoparticles into the acrylic resin improve the physical and thermal stability of the prosthesis?

1.4 Research objectives

The objectives of the study are:

i). To incorporate silver nanoparticles into acrylic resin.

ii). To assess the physical and thermal stability of the PMMA-AgNPs prosthetic base.

iii). To determine the effect of AgNPs towards hinding the formation of biofilm on the PMMA-AgNPs prosthetic surface.

1.5 Significance of research

PMMA is a suitable material in manufacturing complete denture structures and removable devices, due to its intrinsic material properties and high biocompatibility (Dogna *et al.*,2014). Unfortunately, PMMA dental prosthesis are prone to bacterial biofilm colonization, leading to severe oral infections. The scientific perspective of this study is to assist patient who wear total prosthesis manufactured by AgNPs- PMMA to prevent oral infections. Moreover, this study attempts to improve the previous method in incorporating AgNPs into PMMA made denture and improve its thermal and physical properties.

1.6 Scope of the research

This project aimed to develop a biocidal polymer based on the incorporation of silver nanoparticles into polymethylmethacrylate resin and the production of total dentures with the same material. This study focused on the incorporation of silver nanoparticles with PMMA and the evaluation of the thermal and chemical stability of AgNPs- PMMA.

The scope of the study was depended on the method of incorporation and polymerization of AgNPs in polymethacrylate resin (PMMA) which would be included in dental prosthesis manufacturing to subsequently confirm the antimicrobial action of AgNPs. The current research was carried out in the laboratories of the scientific and technical research center in physico-chemical analysis (C-R-A P-C Algeria). The following analyses were used to achieve the research objectives:

i). X-ray diffraction: Provides information on crystal structures, phases, preferred crystal orientations and other structural parameters such as crystallinity, stress and crystal defects.

ii). Transmission electron microscopy (TEM): Identification of nanoparticle size, agglomeration, hardness effects and crystal defects.

iii). Scanning Electron Microscopy (SEM): provides high resolution, deep field images of the sample surface and near surface, elemental microanalysis (EDS) and particle characterization.

iv). Thermogravimetric analysis (TGA): the process of continually measuring the evolution of the weight or mass of a sample exposed to heating due to polymer disintegration (AgNPs-PMMA).

v). Differential Scanning Calorimetry (DSC): allowing the determination of the glass transition temperature, melting and crystallization of the polymer (AgNPs-PMMA).

vi). Optical properties by UV - Visible spectrophotometry: is used to determine the optical properties of colloidal AgNPs and the absorption wavelength.

A thorough microbiological analysis, including bacterial culture on blood agar and bacterial identification by the analytical profile index (API) method, was performed at the Microbiology Laboratory C.H.U Annaba, Algeria.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Historically, colloidal silver was used to treat various diseases from the late 19th century to the 1940s with the development of modern antibiotics and concerns about its side effects (Liuetal *et al.,* 2015). Recently, silver nanoparticles started to be used in the pharmaceutical industry (Zhang *et al.,* 2016). While silver has long been used for medical purposes, silver nanoparticles have proven to be real remedies for certain diseases (Dogna *et al*.,2014). Silver in colloidal form was able to initiate certain antioxidant enzymes that have been recognized as important modulators of AgNPs- induced oxidative stress. Two of them, catalase and superoxide dismutase, play an important role in maintaining the level of reactive oxygen species in organisms (Crooks *et al.*,2013). They are used as bioindicators of increased reactive oxygen species production, as they can also cure certain diseases such as inflammation, skin problems or bacterial infections (Crooks *et al.,* 2013).

Since the 1990s, "colloidal silver" has been presented as alternative medicine (AlešPanáček *et al.,*2004), often presented as "curing everything", which has never been scientifically proven. However, colloidal silver has an invitro antibacterial effect, including on multidrug-resistant strains of *Staphylococcus aureus* (AlešPanáček *et al*.,2004). In the 1970s, Dr Robert O. Becker reported positive results in treating "incurable" infections with colloidal silver (Philip *etal.,*2010). In the 1980s Dr Larry C. Ford documented more than

650 different pathogens were killed by silver nanoparticles within minutes in vitro study (Cierech *et al.*,2016). At the same time, it can cause severe and potentially irreversible side effects such as argyrism (NCCIH *et al.*,2016). The oral environment is strongly influenced by ingested food. It controls the formation of microorganisms in the presence of water (which constitutes 99% of saliva) and many nutrients, in the body temperature, which most microbes prefer (Linda *et al.,* 2013). However, this microbiota must form solid biofilms resistant to saliva (Wang *et al.,* 2014). *Actinomyces, Arachnia, Bacteroides, Bifidobacterium, Eubacterium, Fusobacterium, Lactobacillus, Leptotrichia, Peptococcus, Peptostreptococcus, Propionibacterium, Selenomonas, Treponema, Veillonella* (Sutter *et al.*1984), or *Porphyromonas gingivalis*,1984), or *Porphyromonas gingivalis* are among the anaerobic bacteria that lead to gingipains and worsen the condition of the oral mucosa (Stephen *et al.,* 2019).

The newborn's oral cavity is aseptic, but bacteria will quickly colonise it from the microbiota of the parents and the environment, including *Streptococcus salivarius*. As teeth appear in the first year, the mouth is colonised by *Streptococcus mutans* and *Streptococcus sanguinis*, which live on the teeth surface and the gums. Other strains of *streptococci* adhere strongly not to the teeth but the gums and cheeks. The gingival crevice area (which helps support the teeth) provides a specific habitat for other (anaerobic) species such as *Actinomyces, Arachnia, Bacteroides*, and *Bifid Eubacterium, Fusobacterium*. Puberty is when bacterial and *spirochete* bacteria also colonise the oral cavity. Certain female sex hormones have been shown to alter the nature of subgingival biofilms of plaque between the gum and the base of the teeth (Gusberti *et al.*, 1990).

Li *et al.* (2014) investigated the properties of PMMA-AgNPs acrylic resin. The results suggest that PMMA incorporated with AgNPs could be developed as an antimicrobial, antifungal and biocompatible resin for a dental prosthesis. In addition, they evaluated the effect of PMMA denture resin incorporated with AgNPs on *Candida Albicans* adhesion and biofilm formation. The bioactivity and biomass of *Candida Albicans* and biofilm were found to decrease Significantly with the increasing concentration of the AgNPs solution. The denture base resin incorporated with AgNPs does not influence the adhesion property of bacterial biofilm at lower concentrations, but it showed anti-adhesion activity at higher concentration. Hamada *et al.* (2015) investigated the effect of AgNPs incorporation on the viscoelastic properties of acrylic resin denture base material. The researchers concluded that incorporating AgNPs into acrylic denture base material can improve its viscoelastic properties as there were higher values of storage modulus E', lost modulus E" and loss tangent Tan δ.

In the study carried out by Cheng *et al.,* (2012), about 3 nm of AgNPs were clearly visible and uniformly dispersed in the polymer matrix. Furthermore, the results show that AgNPs are well dispersed in the material with minimal appearance of nanoparticle aggregates, aggregation and dispersion of nanoparticles in polymer-based nanomaterials are governed by the balance between attractive and repulsive forces(Melo *et al.,* 2013).The repulsive forces depend on the nature and size of the grafted polymer, while the depletion forces are mainly due to interactions between the graft and the medium into which the nanoparticles are introduced. Therefore, the aggregation of silver nanoparticles depends on their number concentration, which is defined as the number of constituent entities in a mixture divided by the volume of the mixture and mobility. This is inversely proportional to their diameter (Cheng *et al.*,2012; Li F *et al.*, 2014).

According to Hernández-Sierra *et al.,* (2008), another important characteristic to analyse is the minimum inhibitory concentration (MIC) of AgNPs. The MIC of 25 nm-AgNPs against *Streptococcus mutant's* strains was found by the liquid dilution method. The results show an average MIC of 4.86 ± 2.71 μg/mL, indicating that AgNPs have bacteriostatic effects at low concentrations. In a similar study, Espinosa- Cristóbal *et al.,* (2009) tested different sizes of AgNPs (8.4 nm, 16.1 nm, and 98 nm). The authors reported higher MICs than the Hernández-Sierra *et al.,* (2008) study: 101.98 ± 72.03 μg/mL, 145.64 ± 104.88 μg/mL and 320.63 ± 172.83 μg/mL respectively. This was probably due to the methodology, which included sucrose for the growth of *S. mutans*. The authors also verified that the MICs were directly proportional to the size of the particles, i.e., the larger the size, the higher the MI. Therefore, the concentration of AgNPs is proportional to the degree of cytotoxicity, to reduce the toxicity of silver nanoparticles, i.e., a minimum concentration gives a lower degree of toxicity to preserve the effectiveness of the antimicrobial power of silver nanoparticles.

Table 2.1: Antimicrobial tests, evaluation of material properties and application of AgNPs-PMMA.

Authors, publication year	Antimicrobial effect	material properties	application
Acosta Torres *et al.*, 2012	Microbial adherence	Flexural strength, flexural modulus, SEM imaging.	Acrylic resins for dentures
Prokopovich *et al.*,2014	Microbial adherence	Compression test, AFM, inductively coupled plasma mass spectrometry	Bone cement
Lyutakov *et al.*, 2015	Agar diffusion method	AFM, FTIR	Films for dental use
Elashnikov *et al.*,2016	Inhibition zone test	Nanofibers made by electrospinning, SEM and TEM imaging	Acrylic resins for dentures
Petrochenko *et al.*,2015	Dynamic contact conditions test	SEM, inductively coupled plasma mass spectrometry	Bone cement
Nunes de Souza et al., 2018	Qualification of biofilm biomass formation using Crystal Violet staining method;XTT for metabolic activity	Films made using casting method TGA, SEM, NMR	Films for dental use
Siddiqui et al., 2018	Inhibition zone test	UV-visible absorbtion, FTIR, TEM	Acrylic resins for dentures
Slane et al., 2018	Kirby-Bauer disk diffusion assay	TGA, DSC, SEM	Acrylic resins for dentures
Wekwejt et al., 2019	Inhibition zone test	Compression test, contact angle test, SEM	Acrylic resins for dentures

According to Li *et al* (2016), silver nanoparticles exhibit strong antimicrobial activity against gram-positive and gram-negative bacteria, including multi-drug resistant strains, fungi, viruses and parasites. Reports in the literature indicate that electrostatic attraction between negatively charged bacterial cells and positively charged nanoparticles is crucial for the activity of nanoparticles as bactericidal materials (Li *et al.*, 2016). The antimicrobial characteristics of PMMA incorporated with AgNPs can be explained as the ionic elution of the polymer, diffused by water molecules in the aqueous medium. This can be demonstrated when the resin incorporated with AgNPs is used directly in the oral cavity where there is saliva which has been considered as the aqueous medium (Gupta *et al.*, 2008). The antimicrobial effect could also come from biocidal activity between bacteria and nanoparticles (Kumar *et al.*,2008). In all cases, the addition of AgNPs to the acrylic resin would cause physico-chemical changes. The polarity of the modified resin would be more negatively charged, which would cause a repulsive force against the negative bacterial walls of the charge. Due to its considerable antimicrobial effects and low side effects, silver-containing materials are used to prevent colonisation and infection on medical devices (Nam *et al.*,2014).

The compressive strength of a PMMA resin reinforced with silver nanoparticles is significantly higher than that of an unmodified PMMA resin. The dispersion of the nanoparticles in the PMMA acrylic matrix decreases the monomer's reaction and increases the amount of unreacted monomer, acting as a plasticizer. This shows the importance of the additive content of the nanoparticles (Chatterjee *et al.*,2010). The addition of silver particles in the palatal part of the acrylic base of a complete removable maxillary prosthesis is highly recommended due to the favorable effect of silver nanoparticles on improving the thermal conductivity and compressive strength of PMMA, due to the weakness of the maxillary prosthesis to compressive forces (Hamedi Rad *et al.*, 2014).

In dental implantology, silver nanoparticles prevent infections through their antibacterial and antifungal activity (Cierechetal *et al.*, 2016). The nanosilver coating process was used in a study via a physical vaporization system (Lkhagvajav *et al.*, 2015). The applied silver nanoparticles have a thickness of 1 µm. Four nanosilver coated orthodontic brackets were inserted into the dorsal region of each rat in the study group. According to Gamze *et al.*, (2016) the nano-silver-coated orthodontic brackets have no disadvantages in biocompatibility and can be useful in fixed orthodontic treatment.

2.2 Physical and chemical properties of silver

Silver (Ag) is the second element of the first subgroup of the periodic table and is a more reactive noble metal than gold. It has excellent conductivity, a property used in electronics. Silver metal is easily deformed by hammering or stretching and is easily torn (Klöppel *et al.*, 2000). Table 2.2 shows the properties of bulk silver.

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