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REVIEW OF SILVER NANOPARTICLE SYNTHESIS USING LASER ABLATION; ITS CHARACTERIZATION, ANTIOXIDANT AND ANTIBACTERIAL FOR SKIN WOUNDS

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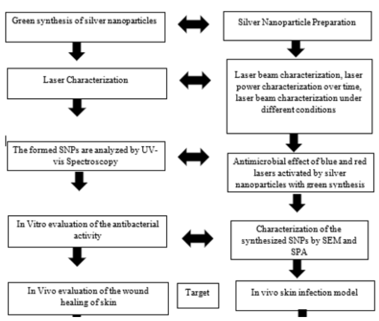
Graphical abstract



Abstract

This comprehensive review paper thoroughly investigates the synthesis of silver nanoparticles (AgNPs) through laser ablation and biosynthesis methods, exploring their potential applications in nanotechnology. The paper discusses the properties of AgNPs, including their antibacterial, anticancer, wound healing, and therapeutic potential. It synthesizes small, spherical particles and analyzes key parameters like laser beam spot size, strength, ablation duration, and green synthesis factors. These analyses are strategically aligned to achieve the desired properties for producing AgNPs efficiently. Simultaneously, green synthesis techniques ensure an environmentally friendly approach, carefully considering factors like time, temperature, and concentration to attain targeted characteristics. The paper employs sophisticated characterization techniques, including dynamic light scattering (DLS), scanning electron microscopy (SEM), and UV-Vis spectral analysis, to comprehensively analyze the synthesized AgNPs. DLS offers insights into size distribution and stability, SEM facilitates morphology visualization, and UV-Vis spectral analysis definitively confirms the presence of silver nanoparticles through characteristic absorption peaks. Expanding the scope, the review delves into the assessment of antibacterial activity exhibited by the synthesized AgNPs. Initial findings suggest a comparable antibacterial efficacy to metal salt solutions, indicating the potential potency of AgNPs against gram-positive (Staphylococcus aureus) and gram-negative (Escherichia coli) microorganisms. Overall, this ongoing review significantly contributes to advancing our understanding of optimized synthesis techniques and the diverse applications of silver nanoparticles in the evolving landscape of nanotechnology.

Keywords: Nanoparticles, Nanotechnology, nanoparticle synthesis, silver nanoparticles; laser ablation

1.0 INTRODUCTION

The prolonged and excessive use of medications is a big phenomenon brought on by chemicals that microbiological organisms have, and resistance in human infections is a key challenge that these anti-resistance antibiotics encounter in the pharmaceutical and medical professions [1]. There is a tendency to want to mix pharmaceuticals with newer, stronger formulations since this influence appears to weaken or neutralize medications, which eventually results in an increase in prescription use. Another issue is that taking these drugs increase their side effects, which leads to the reemergence of Multidrug-Resistant (MDR)bacteria and parasites [2]. An MDR patient can be treated as simply as possible once they become infected because they develop diseases that are the result of primary infections that are more damaging. Not because he needs to spend more time on them, but because he must treat them with broad-spectrum antibiotics. Despite having less impacts, they are costly and hazardous. As a result, it is crucial to develop and modify anti-inflammatory organisms that improve these substances' capacity to combat germs. This component has just recently been the subject of years of research [3].

The most cutting-edge technology available today is nanotechnology, which can be applied to every aspect of human life, including animal, plant, environmental, industrial, and medical applications. Thanks to this invention, human status has altered both now and in the future. To address the issue of the emergence of MDR bacteria, researchers are turning to anoparticles, specifically silver nanoparticles. Hippocrates believed that silver powder had healing and anti-illness properties, and there was a list of remedies for wounds [4]. Silver compounds have a variety of medical applications. Silver compounds are the main line of defense against infected wounds. The greatest and most persistent tarnishing was World War I. The skin and eyes are affected by Argyria or Argyvosi, which is caused by silver deposition brought on by prolonged exposure to silver or silver compounds [5]. Human medicine has used silver as an antibiotic for a very long time. It was developed for use in cardiac equipment, orthopedic reconstructive surgery, bone pros- theses, and catheters.

Ionizable silver has been utilized in textiles for therapeutic purposes to lower the danger of nosocomial infections and for personal hygiene. In water, physiological fluids, and tissue exudates, silver ions and inorganic silver compounds are all ionized [7]. The physiological activity of the silver ion enables it to instantly interact with molecules on the membranes of eukaryotic and mammalian cells, including proteins, residues of amino acids, free anions, and other substances. The genetically determined bacterial (and maybe fungal) easily to silver is connected to the bulk of intracellular silver absorption and silver's capacity to relate with and inevitably denature key enzyme systems. Clinical exposure to silver by eating, cutaneous application, inhalation, urinary, or hematogenous pathways provides minimal danger due to its low toxicity in humans [8].

Silver metal or silver sulphide particles may lodge in a person's skin, eyes, or other organs as a conclusion of continuous intake or consumption of silver preparations, principally colloidal silver (a condition known as argyria). Even when they are not life-threatening, many illnesses are ugly [9]. As soon as silver enters the body, it circulates as a protein complex for the liver and kidneys to eliminate. Induction and binding to metallothionein both affect how much silver is metabolized. This substance promotes tissue regeneration and lowers the cell toxicity of silver. The use of silver in medical equipment or antibiotic fabrics is known to be contraindicated for those with silver allergies [10]. Because of this problem, as well as the negative effects of antibiotics like penicillin and cephalosporins, silver's reputation as a disinfectant was forgotten [11].

New silver was able to reclaim the position it had previously lost as science evolved. According to the findings, modern engineering techniques lacked metallic silver with novel characteristics and forms. The characteristics of antimicrobial silver were enhanced via nanoscale size modification [12]. Nanoscale silver particles and atomic clusters with sizes from 1 to 188 nm that bind to proteins with sulfur on their surfaces change the permeability and shape of bacterial membranes. Numerous researchers have looked at the relationship between cell proliferation and cell death, silver nanoparticles' antibacterial impact on infections, and the role of MDR in the respiratory chain [13]. It also demonstrated that these bacteria, along with Pseudomonas aeruginosa, Escherichia coli ampicillin- resistant, Streptococcus pyogenes erythromycin-resistant, Staphylococcus aureus methicillin-resistant (MRSA), and Staphylococcus aureus vancomycin-resistant (VRSA), are resistant to the effects of silver nanoparticles [14].

Ag-NPs exhibiting significant optical absorption in the visible range have attracted the attention of researchers. They are extensively utilized in many different industries, including as textile engineering, medical implants, the medical industry, electronics, optoelectronics, and sensor technologies, together with solar energy, user products, and water treatment [15]. These characteristics prompted the creation of several Ag-NP manufacturing methods, such as pulsed laser deposition [16], chemical reduction [17], micro-emulsion [18], nonchemical [19], electrochemical [20], solvothermal [21], and photochemical [22].

During the manufacturing of Ag-NP, control over size, shape, and surface functionalization is crucial. The benefits of laser ablation technique over more traditional ones are its ease of adoption, environmental friendliness, and lack of chemical regulators or ions during synthesis. The fabrication of ultra-pure silver nanoparticles can also be accomplished quickly, chemically cleanly, easily, and in a variety of ways using laser ablation [23]. Consequently, it is shown that the laser ablation process is a green, ecofriendly synthetic method. Although pulsed laser ablation has been widely used, continuous wave (CW) laser synthesis of NPs has yet to get much attention. Utilizing a laser to remove a solid's substance (or, very rarely, liquid) surface is known as ablation. It is sometimes referred to as laser blasting or photoablation [24, 25, 26], includes illuminating the surface with a laser beam. The material absorbs laser energy at low laser flux, heating up and evaporating or sublimating as a result. Plasma is frequently produced by the material at high laser flux. A continuous-wave laser beam may also vaporise material if its power is sufficient. When material is removed with a pulsed laser, the phrase "laser ablation" is often employed.

Ultrashort laser pulses, including femtosecond pulses, help treat micromaterials because they cause the least amount of material damage because of the ultrashort light-matter interaction. In contrast, relatively lengthy laser pulses, such as nanosecond pulses, may heat the produced material and thermally modify or damage it [27]. Excimer lasers, which emit deep ultraviolet light with a wavelength of about 200 nm, are the main lasers used in photoablation. Depending on the laser's wavelength, the substance's optical characteristics, and the length of the laser pulse, a single laser pulse may remove a certain quantity of material. The extent to which the laser energy is absorbed has an impact on each of these variables. The entire mass that each laser pulse eliminates from the target is sometimes referred to as the "ablation rate" in scientific contexts. The ablation process can be significantly impacted by the characteristics of laser light, such as scanning velocity and scanning line coverage [28]. The duration and flux of laser pulses can be precisely regulated and range from milliseconds to femtoseconds. Laser ablation is thus particularly advantageous in both professional and academic settings.

Laser Ablation in Liquids (LAL) [29, 30], pulsed laser ablation and excitation of liquid-based nanoparticles is another name for this process [31, 33] or LASiS, or laser ablation synthesis in solution [33, 34], an approach that makes it possible to create pure nanoparticles without using extra chemicals. This method also enables the control of nanoparticle size and form by precisely altering the processing conditions [35]. Due to these qualities, this method is a great substitute for creating nanoparticles that can treat human infections [36]. Several researchers have employed laser ablation in liquids rather regularly to create silver nanoparticles [37,38,39,40,41,42]. Improvements in the original method's productivity or the size of the nanoparticles were made possible by variations [43,44,45].

The effectiveness of laser-produced silver nanoparticles in liquid as a bactericide against a variety of bacteria, gram-positive bacteria, for example Staphylococcus aureus, has already been demonstrated by several researchers [46,47] or Bacillus subtilis [48, 49] along with gram-negative bacteria like Escherichia coli [50,51, 52] or Pseudomonas aeruginosa. To the authors' knowledge, no studies have examined how silver nanoparticles created by liquid laser ablation affect multispecies biofilms.

In this research, we investigate the efficacy of preventing the growth of multispecies biofilms crucial to oral implant development using liquid silver nanoparticles generated through laser ablation and reirradiation, with a focus on addressing peri-implantitis. Our synthesis method employs a laser ablation approach characterized by a straightforward and cost-effective procedure that yields high-purity nanoparticles. This technique allows for the production of nanoparticles with or without a stabilizer. Furthermore, we explore the predictability of nanoparticle creation by adjusting parameters such as fluid medium, pulse repetition rate, pulse duration, wavelength, and spot size during the synthesis process.

2.0 ANTIBACTERIAL INSIGHTS AND EXPERIMENTAL ASSESSMENTS

This We searched for information on the biosynthesis of metallic nanoparticles with antibacterial capabilities in a variety of academic research and collected that data. There were numerous reports on the subject, thus a thorough examination was necessary to incorporate all of the findings in order to draw a conclusion and avoid any informational inconsistencies, ambiguities, or misunderstandings. As advised by Cooper and Koenka [32], this review intends to highlight and classify the antibacterial activity of bio-silver nanoparticles by including all of these exhaustive investigations. The PRISMA criteria were used to construct this summary, as shown in Figure 1.

Formulating the Problem

In the first stage, the method for calculating and measuring the biogenic Ag-NP during the evaluation of the antibacterial activity was developed. This study's focus was widened to consider if Ag-NP may take the role of antibiotics against diverse drug-resistant microorganisms or function as an effective antimicrobial agent when used as a viable therapy.

Literature Searches for Research Syntheses

A thorough literature review was first carried out in December 2019 for the second step. Three computerized databases ScienceDirect, MEDLINE, and Scopus were used to review the pertinent literature. The study used keywords like "biosynthesis silver nanoparticles" OR "silver nanoparticles" OR "biosynthesis" OR "green synthesis" AND "antibacterial activity" OR "antimicrobial resistance" AND "systematic review," as well as Boolean operators, brackets, and insertions as required, as well as MeSH (Medical Subject Headings) terminology. For each database, asservation, or collection of quellings, was built during the search process. Due to the database, each search criterion or query must have its syntax changed. The chosen publications also provide operational definitions for each word. In the end, articles containing information, summaries, and reviewer feedback were included.

The literature search was restricted to English-speaking sources exclusively. The search technique's inclusion and exclusion criteria were created: The following conditions have to be met for inclusion: English publishing, experimental study design, in vitro studies, and publications on biologically generated silver nanoparticles and their antibacterial capabilities all satisfies this condition. The criteria for exclusion were as follows: Studies that (i) didn't conduct in-depth literature reviews; (ii) weren't subjected to peer review; (iii) didn't focus on biosynthesis; (iv) didn't connect their results to antibacterial- reliant results; and (v) weren't published in English. Additionally, eliminated during the choice process were duplicate articles. Two publications have published similar papers having the same original author, study methodology, sample size, and quantity of in-text citations or sources. We conducted in-depth research to find any such papers and excluded them from our review. Each retrieved research article was assessed for inclusion and exclusion using the principal author's name. Additionally, until a solution was found, entire texts were also collected for all such writers. To locate other research publications, the research papers again were examined. To ensure and boost the research's authenticity, the same screening procedure was used for the articles that were recovered once again.

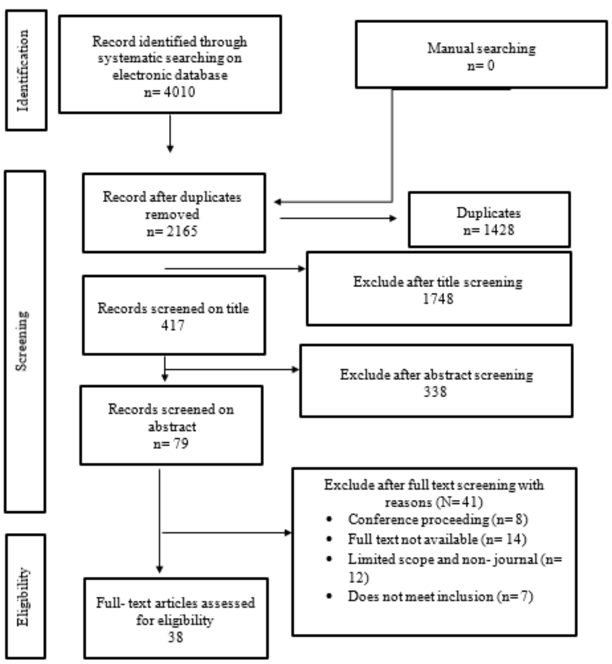


Figure 1 The recommended reporting style for meta-analyses and systematic reviews, or PRISMA

Experimental Procedure

The antimicrobial photodynamic treatment (aPDT) used red and blue LED light to photoinactivate germs like S. aureus and E. coli, and after growing the bacteria with a photosensitizer for two hours, the bacteria were finally ready to be exposed to laser light. In the research, the results of the synthesis were first analyzed using UV-Vis for spectroscopic examination. The light source and sample are irradiated at an ideal fixed distance that is perpendicular to one another [33]. Preparing a culture including bacteria and photosensitizer up to 1 ml and diluting it in 9 ml of physiologically sterile water is the first stage in the irradiation process. In vivo evaluation of the wound healing of the skin in three rats per experimental group was used to divide the rats into the control, infected, and Ag-NP-treated groups. The tests were conducted on female laboratory mice of the BALB/c line. Wistar adult female rats will be kept in stainless steel cages for 12 hours. Pentobarbital injected into rats to anesthetize them, and a 2.5 cm^2 patch of hairless skin will be tape-stripped five times. The animals were inoculated with E. coli and Staphylococcus aureus cultures to start an infection [34].

Laser characterization aims to determine the character of the beam issued. There are four characterizations in the laser performance test, namely laser beam characterization, laser power characterization over time, characterization of laser power and wavelength against distance, as well as irradiation temperature characterization.

The evaluation of organically produced green silver nanoparticles was done using the following characterizations. PSA, FTIR, TIM, SEM, UV-Vis, and FTIR. Pentobarbital injected into rats to anesthetize them, and a 2.5 cm^2 patch of hairless skin tape-stripped five times. Animals inoculated with E. coli and Staphylococcus aureus cultures to start an infection. A post-test for an analysis of variance (ANOVA) was employed in the research (antibacterial and toxicological studies) to determine the importance of variations in group averages. Table 1 illustrates the activity of AgNPs against specific bacterial strains and their impact on various cell lines at different concentrations.

Table 1 AgNPs' activity against specific bacterial strains and its impact on various cell lines at various concentrations

No	First author, year of publication	Country of study	Target Organism	Different Form of Silver	Concentration Range	Effects of AgNPs	NP Size	Study quality
1	Stevens DL, 2014	America	Staphylococcus aureus and Escherichia coli	Silver ions	25–75 µg/mL	Cytotoxicity rises in a concentration-dependent way in the rat alveolar macrophage cell line.	not reported	Good
2	Walker M, 2006	UK	Escherichiacoli	Silver nanoparticles	5, 15, 40, 125 µg/mL	Due to mitochondrial depolarization, cytotoxicity developed.	not reported	Poor
3	Lee SH, 2019	USA	RNA viruses	Silver ions	20–250 µg/mL	Induced apoptosis and necrosis in Hematopoietic stem cell (HSC) cell line	not reported	Good
4	Yin IX, 2020	China	Salmonella typhus, Vibrio cholerae, Pseudomonas aeruginosa, and Escherichia coli	Silver nanoparticles	1, 2, 4 µg/mL	The reduction in cell viability was concentration-dependent.	25 nm and 1–100 nm	Good
5	Zamiri R, 2007	Malaysia	Escherichia coli	Silver ions	0.4 and 0.8 µg/mL	A Murine Macrophages cell line's arrest of the G1 phase of the cell cycle (#RAW 264.7)	40–60 nm	Poor
6	Pandey JK, 2014	India	Salmonella typhi, Staphylococcus epidermidis, Escherichia coli, and	Silver nanoparticles		When compared to the base liquid (de-ionized water), the thermal conductivity of the nanoparticle colloidal solutions (nanofluids) increased by 16% and 27% for CW	10–20 nm	Good
			Streptococcus aureus			and pulsed laser preparations, respectively.		
7	Fernández AM, 2018	Spain	Trichoderma species, Fusarium semitectum, Phoma glomerata, Phoma herbarum, and Candida albicans	Silver nanoparticles		The obtained nanoparticles were made up of rounded Ag nanoparticles with sizes between a few and 50 nm.	not reported	Poor
8	Iravani S, 2014	Iran	Pathogenic fungus Aspergillus flavus and Aspergillus niger, S. aureus, P. aeruginosa, and	Silver nanoparticles		The strongest antibacterial effects were seen in nanoparticles that had been irradiated three times. By modifying dental implants in this manner, peri-implantitis may be avoided.	not reported	Good
9	Pal S, 2007	Korea	Bacillus subtilis, Enterococcus faecalis, Klebsiella pneumoniae, S. aureus, E. coli,	Silver nanoparticles		The outcome demonstrated that 99.6% to 100% of the bacteria could be killed by the created silver nanoparticles.	not reported	Poor

3.0 SYNTHESIS METHODS OF SILVER NANOPARTICLES

The ways to make Ag-NPs, including chemical, photochemical, biological, physical, and ones are existing. Each strategy has benefits and drawbacks. The following are the synthetic approaches with the most frequently encountered issues, Specifically, the Ag-NPs' costs, stability, scalability, particle sizes, and size dispersion:

Chemical Method

Chemical approaches are preferred among published techniques for the production of Ag-NPs because of their ease of solution synthesis and effectiveness [53]. These techniques are being used by numerous academic institutions and research teams to create Ag-NPs of varied forms and sizes. In one experiment, polyvinylpyrrolidone (PVP) polymer was used to reduce silver (NO_3) with ethylene glycol using the "polyol process" to produce monodisperse silver nanotubes [54]. Ethylene glycol has been shown to function in this process as both a reducing agent and solvent. The molar ratio of PVP and Ag (NO3) had a substantial impact on the nanotubes' size and shape. The geometry (form and size) of Ag-NPs may thus be affected by changing the experimental conditions. The polyol method was changed to produce rounded Ag-NPs with controlled size and monodispersing via precursor injection. Particles having a diameter of 20 nm or less were created using this technique. Controlling factors for the precursor injection technique55. In a different approach that has been published, liquid paraffin, oleyl amine, and Ag (NO3) were used to create monodispersed Ag-NPs. High temperatures were managed via the Oley alminoprofen system, this was essential in figuring out how big the created Ag-NPs' particle size was. To continue high temperatures and, secondly, to avoid using solvents that would interfere with the entire synthesis process, liquid paraffin was used 56. The three variables (stages) that are typically necessary are the Ag precursor employed in the chemical manufacture of Ag-NPs, the stabilizing agents, the reducing agents.

The shape of the resultant Ag-NPs is controlled by the nucleation and subsequent stacking of the Ag nuclei. Controlling the nucleation stage and nuclear stacking is crucial since these processes are influenced by experimental variables such precursor, temperature, pH, and reducing agents [57]. In more recent years, Trisodium citrate was used to stabilize the Ag-NPs, and sodium borohydride was used to reduce them, and Ag (NO3) as a catalyst. By altering the experimental conditions, the diameters of Ag-NP were changed to vary from 5 nm to 100 nm. They also explained the relevance of the newly created Ag-NPs' size- and dose-dependent characteristics. Data analysis showed that, in comparison to their larger counterparts, AgNPs with modest diameters exhibit a good antibacterial effect [58]. Colloidal solutions produced by reducing silver salt go through two nucleation phases and growth. The researchers also showed that the phases, as mentioned above, significantly influence the form and size of the created Ag-NPs. Additionally, synthesizing monodispersed Ag-NPs of the same size and monodispersing properties requires the simultaneous creation of nuclei. By doing this, it's likely that all of the nuclei will be roughly the same size or close to it, after which there will be additional growth. Temperature, precursors, pH, reduction (ethylene glycol, NaBH4, and glucose), stabilising (PVA, PVP, and sodium oleate), and other reaction factors may all be changed to influence how nuclei initially form and subsequently develop [59, 60].

Physical Method

Metal nanoparticles are typically created using physical processes such as evaporation-condensation, this is possible in an atmospheric pressure tube furnace. Within a boat that is immediately positioned above the furnace, a carrier gas is created out of the source material. Numerous substances, like Au, Ag, fullerene and PbS, have been made into nanoparticles via the evaporation/condensation process in the past61. A tube furnace has a number of drawbacks when generating silver nanoparticles (AgNPs), including taking up a lot of space, the process of the temperature rising around the source material is time- and energy-consuming. The average tube furnace takes several tens of minutes and more than a few kilowatts of power to reach a stable working temperature.

Utilizing a small heating area ceramic heater to produce AgNPs. The evaporated vapor can cool at the appropriate pace because there is a significantly sharper temperature gradient at the heater surface than there would be in a tube furnace. This enables the high concentration production of tiny nanoparticles. This approach may be useful for a variety of activities, such as time-consuming tests for toxicity studies based on inhalation and as a tool for calibrating nanoparticle measuring equipment [62].

Bulk metallic materials in solutions have also been laser-ablated to produce AgNPs [63, 64]. Numerous variables, The laser's wavelength, the length of its pulses (in the femtosecond, picosecond, and nanosecond timescales), The fluctuations, the duration of the ablation period, and the arrangement of the effective liquid medium greatly affect the characteristics of the fine metal particles and the effectiveness of the ablation [65, 66].

The fluence of the laser is one of the most important components. In fact, the target must be struck with a minimum amount of strength (or fluence) in order to release metal particles. According to studies, the average nanoparticle size often increases with laser intensity and then decreases when the intensity only slightly exceeds the laser damage limit.

Photochemical Synthesis

A photophysical technique and a photochemical technique are the two basic strategies used for the synthesis of Ag-NPs in photochemical techniques. Photochemically activated intermediates, such as radicals, are produced during the photoreduction of precursors or Ag ions in photochemical techniques, leading to the creation of Ag-NPs [57]. In one technique, UV light and an aqueous solution containing the stabilizing chemical Triton X-100 were used to create Ag-NPs. The study's surfactant was crucial in preserving the produced Ag-NPs' stability, monodispersed, and uniform size74. In a different approach that has been published, UV light was used to create Ag-NPs from an aqueous alkali solution that contained AgNO3 and carboxymethylated chitosan (CMCTS). Additionally, to serving as a reducing agent, CMCTS also improved the stability of the synthesized Ag-NPs.

The manufactured Ag-NPs have a diameter of less than 10 nm. For more than six months, the produced Ag-NPs in the alkali/CMCTS alkali solution remained stable [75]. Ag-NPs may be produced using a better photochemical process, Balan *et al*. presented a direct photoreduction of $AgNO_3$ utilizing a laser source that can produce light in the near infrared (IR) range. In order to make dyes photoactive, they [76]. The great purity and ease of processing of the generated Ag-NPs were the benefits of photochemical methods for their production. Ag-NPs, which were also produced by UV radiation with the aid of reducing agents, may be produced using a variety of reaction media, including glass, micelles, polymer, emulsion, and others [77].

Biological Synthesis

precursors, a reducing agent, a stabilizer/capping agent (PVP), and a method for producing Ag-NPs are required to avoid agglomeration. Biomolecules are taking the role of the typical reducing and stabilizing agents in biological processes. Yeast, fungi, Algae, and bacteria are a few of the plants used as reducing and stabilizing agents in biological processes to create Ag-NPs [78]. By using an Ag (NO_3) solution as a precursor, the metal-reducing agent Shewanella oneidensis produced Ag-NPs. The Ag-NPs produced had uniform dispersion, a surface area greater than 15 nm2, a spherical shape, and enhanced stability. Ag-NPs are produced using techniques that are much less expensive, incredibly reproducible, and energy-efficient than traditional procedures [79]. In a different investigation, Ag-NPs were produced from precursors of Ag (NO_3) by the fungus Trichoderma viride [80].

With particle sizes less than 50 nm, the biosynthesized Ag-NPs had an extremely variable shape. Additionally, stable Ag-NPs smaller than 20 nm were produced utilizing Ag (NO3) as the precursor by airborne bacteria (Bacillus sp.). Biosynthesized Ag-NP accumulation occurs in the periplasmic region of the bacterial cell, which is the gap between the outer and inner membranes. Additionally, it was discovered that when Ag (NO3) phyllanthin extract was reduced at room temperature, AgNP was created in a spherical shape. The concentration of phyllanthin extract controlled the Ag-NPs' size and form81. Venkata Subbaiah and Savithramma discovered in a different investigation that Cadaba fruticosa leaves may also be used as a source of AgNPs when utilizing Ag (NO3) as a precursor. The biologically created nanoparticles were particularly effective at killing bacteria82.

4.0 CHARACTERIZATION OF SILVER NANOPARTICLES

Characterizing nanoparticles is necessary for comprehending and managing their production and use. Several techniques are used to characterize materials, comprising X-ray photoelectron spectroscopy (XPS), Fourier transform infrared (FTIR), powder X-ray diffractometry (XRD), dynamic light scattering (DLS), atomic force microscopy (AFM), and UV-Vis spectroscopy [51, 52]. These techniques may determine various metrics, includes pore size, surface area, crystallinity, crystal form, crystallinity, and particle size. These methods may examine nanoparticle and nanotubes' orientation, intercalation, and dispersion in nanocomposite materials. To determine the morphology and particle size, for instance, TEM, SEM, and AFM might be utilized. In contrast to traditional microscopes like SEM and TEM, AFM has the advantage of obtaining three-dimensional images, making it feasible to measure particle height and volume. Additionally, dynamic light scattering is used to calculate the distribution of particle sizes. Additionally, UV-Vis spectroscopy uses the presence of plasmon resonance to assist sample creation, and X-ray diffraction evaluates crystallinity.

5.0 USES FOR SILVER NANOPARTICLES

AgNPs have been widely employed in a number of environmental applications as anti-bacterial agents, covering the health sector, food preservation, textile finishing, and other industries It's important to remember that despite years of usage, there is still controversy around silver's toxicity. Products created using AgNPs have received approval from several prestigious agencies, comprise the US FDA, US EPA, the SIAA of Japan, and the FITI Testing and Research Institute, as well as Korea's Testing and Research Institute for Chemical Industry [83, 84]. Many applications, including water filtration, sanitizing household and medical equipment, and cleaning home appliances, used AgNPs as anti-bacterial agents [85, 86]. This prompted the textile industry to incorporate AgNPs into a variety of textile materials. Silver nanocomposite fibers with woven silver nanoparticles were produced using this technique [87]. High antibacterial action against Escherichia coli was shown by cotton fibers containing AgNPs [88]. In addition, AgNPs' electrochemical properties have been used to create nanoscale sensors with shorter response times and lower detection thresholds. As an illustration, AgNPs were electrodeposited onto alumina plates employing a highly sensitive to hydrogen peroxide gold micro-patterned electrode [89].

The chemical characteristics of bulk materials are different by nanoparticles' catalytic activity. For instance, the bleaching of organic hues is greatly improved when potassium peroxydisulfate is combined with silver-containing nanoparticles in an aqueous solution at room temperature [90]. In addition, it was shown that AgNPs were more effective at catalyzing the chemiluminescence produced by luminol-hydrogen peroxide systems than Au and Pt colloid [91].

Alkaline aqueous solutions are used to accelerate the reduction of 4-nitrophenol with NaBH4, halloysite nanotubes (Ag/HNTs) are used to hold together silver nanoparticles with an estimated 11% silver content. Plasmons, oscillations collect free electrons inside the metal nanoparticles, setting up the plasmon resonance on the surface of the nanoparticles. This greatly affects the properties of optical nanoparticles. It is generally recognized that these variables have an impact on metallic species, the environment, nanoparticle size and shape, as well as plasmon resonant peaks and line widths. For instance, a revolutionary optical data storage device might be built on nanoclusters made of 2–8 silver atoms. Electroluminescent displays and biological labeling can both be made using the clusters' fluorescent emissions [92, 93].

Silver Nanoparticles Antibacterial Applications

a. Mechanisms of Antibacterial Action

Three mechanisms observed either jointly or separately by which AgNPs exercise their antibacterial effect are now the majority of the evidence in the literature [94,95]. According to the first theory, across the inner membrane after slipping through the outer membrane, AgNPs perform their membrane-level actions. Here, their adhesion weakens and destabilizes the cell, increases membrane permeability, results in cellular content leakage, and ultimately leads to cell death [96,97]. In addition, it has been demonstrated that AgNPs bind to proteins that contain sulfur in bacterial cell walls, which might harm the structure and break the cell wall.

According to the second method, nanoparticles might enter cells and alter the structure and function of intracellular materials including proteins and DNA by preferentially interacting with their sulphate or phosphorus groups. Nanoparticles that enter and pass the cell membrane may alter its composition and permeability. Similar to how thiol groups in enzymes interact with them to create free radicals and reactive oxygen species, which may harm intracellular machinery, start apoptosis, and modify the inner membrane's respiratory chain. The third stage, assumed to occur simultaneously with the previous two processes, is the nanoparticles' release of silver ions. These ions may interact with biological elements and alter membranes, metabolic pathways, and even genetic material because of their size and charge [98,99,100].

b. Elements Affecting AgNPs' Antibacterial Activity

AgNPs' antibacterial activity has been found to be regulated by their molecular make-up as well as their chemical size, charge, and surface.

Lu *et al*. looked into how the size of AgNPs affected their ability to fight off the bacteria that cause periodontal and dental caries problems [101]. AgNPs of 5, 15, and 55 nm were created by chemically reducing polyvinylpyrrolidone (PVP), and their antibacterial activity against *Aggregatibacter actinomycetemcomitans, Fusobacterium nucleatum, Streptococcus mutans, Streptococcus sanguis,* and *E. coli* was assessed [102]. With the exception of the assayed strain of E. coli, whose MIC value was 6 g/mL, all of the pathogens that were tested had minimum inhibitory concentrations (MIC) that varied from 25 to 50 g/mL. This demonstrates that the antibacterial effect was greater for the 5 nm nanoparticles. There is a significant discrepancy in the MICs of the several studied microorganisms because E. coli is anaerobic in nature, while the other pathogenic bacteria are aerobic. The study's hypothesis states that this effect may be due to AgNPs' decreased antibacterial activity as a result of oxidation in aqueous medium when exposed to air.

In another study, AgNPs of various sizes were made using the same ingredients and basic procedures, but with different pH levels and stabilizer/reducing agent ratios. Following that, it was determined how well gram-positive and gram-negative bacteria responded to nanoparticles between 5 and 100 nm in size [103]. For two strains of Escherichia coli, Bacillus subtilis, and Staphylococcus aureus, the range of the MIC was 20 to 110, 60 to 160, 30 to 120, and 70 to 200 g/mL, with the first value corresponding to nanoparticles that were smaller (5 nm) and larger (100 nm), respectively [104]. Additionally, it was shown that, with the exception of S. aureus, whose MBC exceeded 200 g/mL, all of the organisms under study exhibited bactericidal values between 30 and 140 g/mL, the MIC data showed that size significantly affected antibacterial activity [105]. The increased surface area that smaller nanoparticles were available for direct contact with bacterial cells was the explanation for this association.

c. Ag-NPs's Mechanism of Action against Microbes

No matter which bacterial strains are antibiotic-resistant or not, silver (Ag) and specifically silver nanoparticles (Ag-NPs) have a well-known antibacterial effect in the scientific community106. The exact process is yet unclear, although it could be linked to how silver (Ag) ions interact with certain bacterial strains, such yeasts and trypanosomes, where a buildup of AgNPs in the aqueous solution leads the cell's enzymes and proteins to become saturated103. The method was proposed by the scientists in their published research, and it shows that DNA and RNA, also to modifications in the nuclear membrane and cell wall brought on by Ag-NPs, are what essentially slow down bacterial cell development. There are three possible methods for using Ag-NP particles to kill bacteria in the meanwhile. (1) The first proposed explanation is that Ag-NPs' adhesion to the bacterial cell wall (induced by the microscopic particle size) restricts bacterial cell development and reproduction, changing the cell wall so that the interior is no longer capable of providing protection for the inside of the cell107. (2) According to the authors' second postulated mechanism, the entry of Ag-NPs into the bacterial cell alters the DNA, delaying proper function and ultimately leading to the cell's demise. DNA damage is caused when silver nanoparticles breach the bacterial cell wall. (3) In the third hypothesized mechanism, it was claimed that interactions between Ag+ ions and sulfur-containing proteins found in the bacterial cell wall result in the breakdown of the bacterial cell wall. It is believed that this process is the primary mechanism underlying the antibacterial action [108].

d. Ag-NPs Role in Medicine

The average size of the nanoparticles has been shown to grow as the laser fluence rises and to be lowest for fluencies that aren't too much beyond the laser breakdown threshold 109. After analysing the data, the researchers concluded that Ag-NPs' antibacterial efficacy was dose-dependent (concentration-dependent) against E. coli. When the experimental circumstances were ideal, they noticed that Ag-NPs were adherent to the gram-negative bacteria's (E. coli) cell wall and caused the bacterial cell to perish110. In a separate published work, scientists explored with numerous gram-negative bacterial species to identify the Ag-NPs [111] size-related properties. Their study showed that the size of the Ag-NPs plays an important role in preventing bacterial cells from carrying out their special task. In addition, scientists found that the smaller particles can easily attach to the bacterial cell wall, prevent the bacteria from breathing, make them permeable, and release gold ions from the Ag-NP particles. In addition, another study studied the effect of Ag-NPs on gram-positive and gram-negative bacteria to find out how they affect dose. The study found that gram-positive bacteria such as S.aureus were more easily suppressed than gram-negative bacteria such as E.coli. Figure 2 shows a graphical representation of the antimicrobial effect of Ag-NP. Ag-NP kills bacterial cells by binding to sulfur in the proteins that make up the bacterial cell wall.

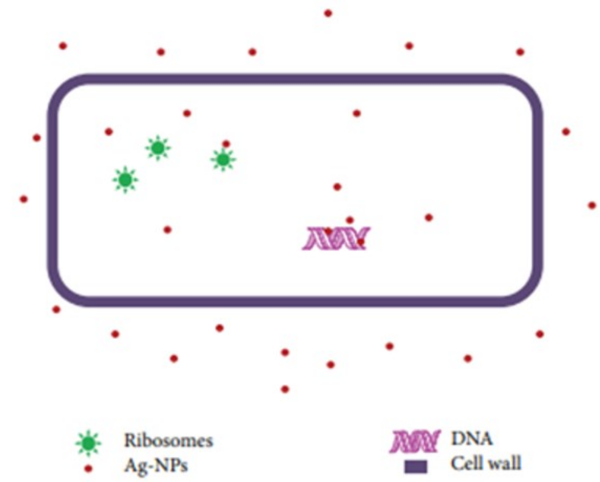


Figure 2 Ag-NPs' antibacterial action in a schematic form Ag-NPs bind to a bacterial cell's cell wall via sulfur found in the protein that makes up the bacterial cell wall, basically leading to bacterial cell death [112]

Ag-NPs also prevent protein synthesis and physically hurt the bacterial cell's interior by puncturing the cell wall and membrane [113]. Ag-NPs' pattern of adherence and penetration into the bacterial cell wall, which eventually results in aberrant function, has been proposed as one theory for the likely mechanism causing the antibacterial action of Ag-NPs [114]. Ag-NPs' antibacterial activity is morphology- and structure-dependent [115].

6.0 LASER ABLATION

When removing material from a solid (or sometimes liquid) surface via laser ablation, photoablation, or laser blasting, the surface is subjected to a laser beam [16, 117, 118]. At low laser flux, the substance absorbs laser energy, which causes it to heat up and evaporate or sublimate. Typically, the substance undergoes a plasma transformation at high laser flux. If the laser intensity is strong enough, vaporizing material using a continuous-wave laser beam is feasible. Due to the ultrashort light-matter interaction, ultrashort laser pulses, such as femtosecond pulses, are appropriate for processing micromaterials because they result in minimum material damage during processing. In contrast to relatively lengthy laser pulses, such nanosecond pulses, which may heat and thermally modify or harm the treated material, "laser ablation" refers to the removal of material by a pulsed laser119. The primary lasers used in photoablation are excimer lasers with deep ultraviolet radiation with a wavelength of about 200 nm.

The quantity of material that can be removed by a single laser pulse depends on the material's optical properties, the laser's wavelength, and the length of the pulse. How much of the laser energy is absorbed affects each of these variables? In this context, the term "ablation rate" refers to the entire mass that each laser pulse removes from the target. The parameters of laser radiation, such as the rate of laser beam scanning and the width of the scanning lines, may have a major impact on the ablation process [120].

The duration and flux of laser pulses can be precisely regulated and range from milliseconds to femtoseconds. Laser ablation is therefore extremely helpful in both academic and professional situations [121].

Laser Ablation Applications

Laser ablation is most often used to precisely remove material from solid surfaces. Examples include laser drilling, which uses pulsed lasers to make extraordinarily tiny, deep holes in rigid materials. Dental enamel is a fragile or heat-sensitive material. Thus, laser drilling is suited since it swiftly removes the material, and the surrounding material absorbs very little heat. A number of researchers have used gas condensation and laser ablation to create metal, metal oxide, and metal carbide nanoparticles [122].

Additionally, layers have the option of absorbing CO2 or Nd: Without harming the underlying surface, surface cleaning, coating removal, and surface priming may all be done using YAG pulsed lasers, particularly on metal. One pulse from a powerful laser might clear a lot of junk. Low-powered lasers use a lot of quick pulses that can be scanned over a surface. In some fields, laser cleaning may be used in conjunction with laser ablation. The Narran ROD 500 Industrial 500W Cleaning Laser is seen in Figure 3.

Figure 3 Narran ROD 500 Industrial 500W Cleaning Laser 16

One advantage is the absence of solvents, which guarantees that operators are not exposed to chemicals and makes it ecologically safe (assuming that no dangerous items are vaporized). Compared to dry media or dry-ice blasting, operating expenses are lower, but capital investment costs are substantially greater. Compared to abrasive procedures, the process is more delicate; for instance, carbon fibers within composite materials are not harmed. The target only slightly warms up.

Another class of applications for laser ablation involves shaping the removed material into new shapes that are either difficult or impractical to create using existing techniques. One recent instance is the creation of carbon nanotubes.

Additionally, the restoration of paintings, sculptures, and frescoes as well as the removal of oil or grease from various surfaces are all accomplished with the help of laser cleaning. Because it just slightly damages the mold's surface, laser ablation is one of the favored techniques for cleaning rubber moulds.

Guo *et al*. published the findings of their early investigation on the use of a laser to ablate blocks of pure graphite, and later graphite combined with catalytic metal, in March 1995 [123]. Cobalt, niobium, platinum, nickel, copper, or a binary combination of these metals may be used to make the catalytic metal. The composite block is made by mixing metal powder with carbon cement and graphite powder to form a paste. After that, the paste is put into a cylinder-shaped mould and cooked for a long period. After the graphite block has solidified, a laser is pointed at it inside of an oven while argon gas is diverted in the laser's direction. The oven is heated to a little under 1200 °C. Carbon nanotubes are created during the laser's vaporization of the target. The gas flow then transports these nanotubes to a cold copper collector. Carbon nanotube fibers are deposited in an ad hoc and twisted fashion, similar to how carbon nanotubes made using the electric-arc discharge process are. Graphite and metal catalyst particles are combined to form a block to form single-walled nanotubes, while multi-walled nanotubes start off as pure graphite.

By removing a source of the coating material to allow it to settle on the area to be coated, pulsed laser deposition (PLD), a particular kind of physical vapor deposition, is utilized in this sort of application to generate coatings124 and can produce coatings from substances that are difficult to evaporate in other ways. Some forms of high-temperature superconductors and laser crystals are produced using this method [125].

In remote laser spectroscopy, the surface material is abraded by a laser to form a plasma; The wavelengths of the light that the plasma produces are then examined to identify the composition of the surface. In order to make patterns, dichroic filters' coatings are selectively removed using laser ablation. This device is utilized for machine vision instrument calibration or stage lighting for high-dimensional projections.

a. Propulsion

Finally, since the ablated material expands and exerts a strong pressure pulse on the surface underneath it, you may use laser ablation to apply force to a surface. The result is comparable to hammering on the surface. This procedure, which is also one of a laser weapon's damaging mechanisms, is employed in industry to work-harden metal surfaces. It also serves as the foundation for spacecraft pulsed laser propulsion.

b. Manufacturing

Processes for removing thermal barrier coatings from high-pressure gas turbine components using laser ablation are currently being developed. TBC removal can be accomplished with little harm to the parent material and underlying metallic coatings because of the low heat input.

c. 2D Materials Production

Black phosphorus, for example, can be effectively exfoliated into its 2-dimensional (2D) form by laser ablation in the liquid phase. The solvent and laser intensity may be changed to alter the 2D materials' thickness and lateral dimensions [126].

7.0 LASER ABLATION-GENERATED SILVER NANOPARTICLES

Laser ablation in liquids (LAL) technique permits the manufacture of pure nanoparticles without the need of extra chemicals [127,228,129], also referred to as LASiS (laser ablation synthesis in solution1 [30,131] or Liquid Nanoparticle Excitation and Pulsed Laser Ablation (PLAL) [132,133]. By carefully adjusting the processing settings, this technique also enables the control of the nanoparticles' size and shape [134]. These qualities make this method a great substitute for creating nanoparticles to treat human illnesses [135]. Many researchers have frequently used laser ablation in liquids to produce silver nanoparticles [136,137,138]. Variations allowed us to increase the productivity of the original process or the size of the nanoparticles [139,140].

Numerous studies have already demonstrated the potency of liquid laser-produced silver nanoparticles as bactericides against a range of bacteria, including gram-positive bacteria like Staphylococcus aureus [141,142] or Bacillus subtilis [143] and gram-negative bacteria such as Escherichia coli [144] or Pseudomonas aeruginosa. As far as the writers' knowledge goes, no studies have looked at how laser-produced silver nanoparticles in liquids affect the development of multispecies biofilms.

This study's goal is to determine how effectively multispecies biofilms connected to oral implant peri-implantitis may be inhibited by silver nanoparticles created by laser ablation and re-irradiation in liquid [145]. The highly significant oral bacterial species Streptococcus oralis, Actinomyces naeslundii, Veillonella dispar, and Porphyromonas gingivalis are all included in this multispecies biofilm model. Ag-NPs' ability to prevent the growth of biofilms on single- and multiple-species of Staphylococcus aureus was tested [146].

Following the previously described procedure, laser ablation and re-irradiation in water produced silver NPs (see Figure 4). The process is succinctly explained here for more clarity.

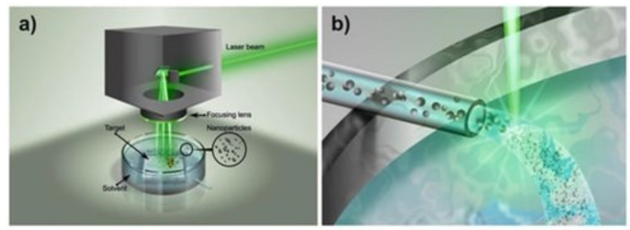


Figure 4 Ag-NPs were produced using two different methods: (a) laser ablation in water, and (b) re-irradiation [147]

A target was created by cleaning and sonicating a silver foil with a purity of 99.99% to use two distinct diode-pumped Nd: YVO4 laser sources to laser ablate the target. A visible laser with a 532 nm wavelength corresponding to the electromagnetic spectrum's green band was first employed. This laser produced pulses with an energy of 0.26 mJ and a 14 ns pulse width.

The second laser source used to create the pulses had a wavelength of 1064 nm, a power of 0.03 mJ, and an 800 ps duration. These pulses were produced in the infrared (IR) spectrum. The green nanosecond laser produced a spot with a diameter of 132 meters and fluence of 1.90 J/cm^2 when it was focused on the silver target's surface. The focused 196 nm laser spot of the IR-Picosecond laser is at that wavelength and has a fluence of 0.09 J/cm^2. Two distinct samples of Ag-NPs (G0 and IR0) in colloidal suspension were created as a consequence of the laser ablation procedure [148].

The upper surface of the silver target served as the focus of all experiments. Similar to this, the laser beam continued to scan the item at a pace of 50 mm/s throughout the laser ablation procedure. Each sample underwent LASL processing for the amount of time necessary to produce silver nanoparticles that were 300 mg/L concentrated.

Using the same laser source, a part of each created colloidal solution was used to create colloidal suspensions of resized Ag-NPs (G1, IR1, and G3, IR3). Discs of titanium with a thickness of 1 mm and a diameter of 25 mm were exposed, the different Ag-NP groups were immobilized, or grade 2 medical titanium, to conduct the bacteriological tests. These titanium discs underwent a 15-minute ultrasonic cleaning procedure with methanol, followed by a thorough washing in ultrapure deionized water to eliminate any impurities. Three titanium discs and 50 mL of each prepared colloidal solution were used to immobilize the Ag-NPs. The colloidal solution was applied evenly to the titanium discs, and they were then allowed to air dry at room temperature. Evaporation maintains the nanoparticles' immobilization on the disc's surface.

8.0 CONCLUSION

AgNPs are a fantastic antimicrobial agent and have outstanding antibacterial properties nowadays. They address a number of the requirements necessary for new antimicrobial technologies to be effective, performance against microorganisms, speed of action, and minimal cytotoxicity. Additionally, nanoparticles may be modified to achieve target delivery and selectivity. Their use against bacteria must be watched over and measured in order to avoid germs from being unnecessarily exposed to sublethal nanoparticle doses that may promote the emergence of drug resistance. Utilizing AgNPs lowers the dosages of antibiotics and nanoparticles needed to have an antibacterial impact against different bacteria, reducing the possibility of adverse effects. Finally, nanoparticles have antibacterial effects on a variety of bacterial species, including resistant strains and both Gram-positive and Gram-negative bacteria. Drugs or antibiotics can be carried by complexes of nanoparticles, enhancing the release and selectivity of those substances. During the synthesis process, in these studies used the Laser Ablation method, which can manufacture high purity nanoparticles without a mixing of hazardous substances. Nanoparticles can be created using the laser ablation process with or without the use of a stabilizer. In this study, a low-energy laser is employed. One may see the formation of nanoparticles by varying the fluid medium, wavelength, spot size, pulse duration, repetition rate, and pulse duration. The Porphyromonas gingivalis, an important oral bacterial species, is a part of the multispecies biofilm model, Actinomyces naeslundii, Veillonella dispar, and Streptococcus oralis. Staphylococcus aureus biofilms and biofilms from various species were examined to assess the effectiveness of Ag-NPs in preventing the production of biofilms. In both cases, outstanding antibiofilm activity was observed. Due to the increased biofilm suppression achieved by Ag-NPs of smaller sizes, the triple laser ablation process may be used to create various types of nanoparticles with improved antibacterial capabilities. That might serve as a substitute for silver in light of the widespread usage of this material as an antibacterial agent and the probable emergence of bacterial resistance to it.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] Rahman, M. M., Alam Tumpa, M. A., Zehravi, M., Sarker, M. T., Yamin, M. D., Islam, M. R., Cavalu, S. 2022. An overview Of Antimicrobial Stewardship Optimization: The Use of Antibiotics in Humans and Animals to Prevent Resistance. *Antibiotics*. 11: 5: 667.

[2] Stevens, D. L., Bisno, A. L., Chambers, H. F., Dellinger, E. P., Goldstein, E. J., Gorbach, S. L., Wade, J. C. 2014. Practice Guidelines for the Diagnosis and Management of Skin and Soft Tissue Infections: 2014 Update by the Infectious Diseases Society of America. *Clinical Infectious Diseases*. 592: e10-e52.

[3] Van Duin D., Paterson, D. L. 2016. Multidrug-resistant Bacteria in the Community: Trends and Lessons Learned. *Infectious Disease Clinics*. 30: 377-390.

[4] Malik. S., Muhammad, K., Waheed, Y. 2023. Nanotechnology: A Revolution in Modern Industry. *Molecules*. 28: 661.

[5] Walker, M., Cochrane, C. A., Bowler, P. G., Parsons, D., Bradshaw, P. 2006. Silver Deposition and Tissue Staining Associated with Wound Dressings Containing Silver. *Ostomy/Wound Management*. 52: 42-4.

[6] Durner, J., Stojanovic, M., Urcan, E., Hickel, R., Reichl, F. X. 2011. Influence of Silver Nano-particles on Monomer Elution from Light-cured Composites. *Dental Materials*. 27: 631-636.

[7] Penes O. N., Neagu, A. M., Plata. F., Paun, S. D. 2017. Fabric with Silver Thread Role in the Control of Bacterial Contamination in Critically Ill Patients/Tesaturi cu fir de argint având rol de control al contaminarii bacteriene la pacientii în stare critica. *Industria Textila*. 68: 54.

[8] Naik, K., Kowshik, M. 2017. The Silver Lining: Towards the Responsible and Limited Usage of Silver. *Journal of Applied Microbiology*. 123: 1068-1087.

[9] Hadrup, N., Sharma, A. K, Loeschner, K. 2018. Toxicity of Silver Ions, Metallic Silver, and Silver Nanoparticle Materials After In Vivo Dermal and Mucosal Surface Exposure: A Review. *Regulatory Toxicology and Pharmacology*. 98: 257-267.

[10] Lansdown, A. B. 2010. A Pharmacological and Toxicological Profile of Silver as an Antimicrobial Agent in Medical Devices. *Advances in Pharmacological and Pharmaceutical Sciences*.

[11] Bush, K., Bradford, P. A. 2016. β-Lactams and β-lactamase Inhibitors: An Overview. *Cold Spring Harbor Perspectives in Medicine*. 6.

[12] Lee, S. H., Jun, B. H. 2019. Silver Nanoparticles: Synthesis and Application for Nanomedicine. *International Journal of Molecular Sciences*. 20: 865.

[13] Ahmad, S. A., Das, S. S., Khatoon, A., Ansari, M. T., Afzal, M., Hasnain, M. S., Nayak, A. K. 2020. Bactericidal Activity of Silver Nanoparticles: A Mechanistic Review. *Materials Science for Energy Technologies*. 3: 756-769.

[14] Bruna, T., Maldonado-Bravo, F., Jara, P., Caro, N. 2021. Silver Nanoparticles and Their Antibacterial Applications. *International Journal of Molecular Sciences*. 22: 7202.

[15] Rafique, M., Rafique, M. S, Kalsoom, U., Afzal, A., Butt, S. H., Usman, A. 2019. Laser Ablation Synthesis of Silver Nanoparticles in Water and Dependence on Laser Nature. *Optical and Quantum Electronics*. 51: 1-11.

[16] Russo, R. E., Mao, X. L., Yoo, J., Gonzalez, J. J. 2007. Laser Ablation. *Laser-induced Breakdown Spectroscopy*. 41-70.

[17] Wang, H., Qiao, X., Chen, J., Ding, S. 2005. Preparation of Silver Nanoparticles by Chemical Reduction Method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 256: 111-115.

[18] Zhang, W., Qiao, X., Chen, J. 2007. Synthesis of Silver Nanoparticles Effects of Concerned Parameters in Water/oil Microemulsion. *Materials Science and Engineering.* 142: 1-15.

[19] Darroudi, M., Zak, A. K., Muhamad, M. R., Huang, N. M., Hakimi M. 2012. Green Synthesis of Colloidal Silver Nanoparticles by Sonochemical Method. *Materials Letters*. 66: 117-120.

[20] Starowicz, M., Stypuła, B., Banaś. 2006. Electrochemical Synthesis of Silver Nanoparticles. *Electrochemistry Communications.* 8: 227-230.

[21] Yang, Y., Matsubara, S., Xiong, L., Hayakawa, T., Nogami M. 2007. Solvothermal Synthesis of Multiple Shapes of Silver Nanoparticles and Their SERS Properties. *The Journal of Physical Chemistry C*. 111: 9095-9104.

[22] Zamiri, R., Zakaria, A., Abbastabar, H., Darroudi, M., Husin M. S., Mahdi, M. A. 2011. Laser-fabricated Castor Oil-capped Silver Nanoparticles. *International Journal of Nanomedicine*. 565-568.

[23] Yu, J., and Zhou, X. 2013. Synthesis of Dendritic Silver Nanoparticles and Their Applications as SERS Substrates. *Advances in Materials Science and Engineering*.

[24] Gao, L. 202 2. Dynamics of Drops and Microjets Subjected to Intense Laser Blasts. Polyu Electronic Theses. The Hongkong Polytechnic University.

[25] Maressa, P., Anodio, L., Bernasconi, A., Demir, A. G, Previtali, B. 2015. Effect of Surface Texture on the Adhesion Performance of Laser Treated Ti6Al4V Alloy. *The Journal of Adhesion.* 91: 518-537.

[26] Penide, J., del Val, J., Riveiro, A., Soto, R., Comesaña, R., Quintero, F., Pou, J. 2019. Laser Surface Blasting of Granite Stones using a Laser Scanning System. *Coatings*. 9: 131.

[27] Chichkov, B. N., Momma, C., Nolte, S., Von Alvensleben, F., Tünnermann, A. 1996. Femtosecond, Picosecond and Nanosecond Laser Ablation of Solids. *Applied Physics A.* 63: 109-115.

[28] Pavlovich, V. V., Matveevich, S. A., Tu, H. C., Anatolievich P. A. 2015. Laser Ablation of Monocrystalline Silicon under Pulsed-frequency Fiber Laser. *Journal Scientific and Technical of Information Technologies, Mechanics and Optics*. 97: 426-434.

[29] Neddersen, J., Chumanov, G., Cotton, T. M. 1993. Laser Ablation of Metals: A New Method for Preparing SERS Active Colloids. *Applied Spectroscopy.* 47(12): 1959-1964.

[30] Mohammed, M., Diwan, A., Saleh, S. M., Salih, B. A. S. 2019. Fabrication of Copper Nanoparticles by Pulse Laser Ablation. *Kufa Journal of Engineering*. 10: 1-11.

[31] Boutinguiza, M., Rodríguez-González, B., Del Val, J., Comesaña, R., Lusquiños, F., Pou, J. 2011. Laser-assisted Production of Spherical TiO_2 Nanoparticles in Water. *Nanotechnology*. 22: 195606.

[32] Amendola, V., Meneghetti, M. 2009. Laser Ablation Synthesis in Solution and Size Manipulation of Noble Metal Nanoparticles. *Physical Chemistry Chemical Physics* 11. 3805-3821.

[33] Astuti, S. D., Kharisma, D. H., Kholimatussa'diah, S., Zaidan, A. H. 2017. An in Vitro Antifungal Efficacy of Silver Nanoparticles Activated by Diode Laser to Candida albicans. *AIP Conference Proceedings*.

[34] Astuti, S. D., Mahmud, A. F., Putra, A. P., Setiawatie, E. M., & Arifianto, D. 2020. Effectiveness of Bacterial Biofilms Photodynamic Inactivation Mediated by Curcumin Extract, Nanodoxycycline and Laser Diode. *Biomedical Photonics.* 9(4): 4-14.

[35] Amendola, V., Meneghetti, M. 2013. What Controls the Composition and the Structure of Nanomaterials Generated by Laser Ablation in Liquid Solution? *Physical Chemistry Chemical Physics*. 15: 3027-3046.

[36] Barcikowski, S., Compagnini, G. 2013. Advanced Nanoparticle Generation and Excitation by Lasers in Liquids. *Physical Chemistry Chemical Physics*.15: 3022-3026.

[37] Wagener, P., Jakobi, J., Rehbock, C., Chakravadhanula V. S. K., Thede, C., Wiedwald, U., Barcikowski, S. 2016. Solvent-surface Interactions Control the Phase Structure in Laser-generated Iron-gold Core-Shell Nanoparticles. *Scientific Reports*. 6: 23352.

[38] Fazio, E., Gökce, B., De Giacomo, A., Meneghetti, M., Compagnini, G., Tommasini, M., Neri F. 2020. Nanoparticles Engineering by Pulsed Laser Ablation in Liquids: Concepts and Applications. *Nanomaterials*. 10: 2317.

[39] Rehbock, C., Merk, V., Gamrad, L., Streubel, R., Barcikowski, S. 2013. Size Control of Laser-fabricated Surfactant-free Gold Nanoparticles with Highly Diluted Electrolytes and Their Subsequent Bioconjugation. *Physical Chemistry Chemical Physics*. 15: 3057-3067.

[40] Barcikowski, S., Menéndez-Manjón, A., Chichkov, B., Brikas M., Račiukaitis, G. 2007. Generation of Nanoparticle Colloids by Picosecond and Femtosecond Laser Ablations in Liquid Flow. *Applied Physics Letters*. 91.

[41] Xu, B., Song, R. G. 2010. Fabrication of Ag Nanoparticles Colloids by Pulsed Laser Ablation iZn Liquid. *Advanced Materials Research*. 123: 675-678.

[42] Mendivil, M. I, Krishnan, B., Sanchez, F. A., Martinez, S., Aguilar-Martinez, J. A., Castillo, G. A, Shaji, S. 2013. Synthesis of Silver Nanoparticles and Antimony Oxide Nanocrystals by Pulsed Laser Ablation in Liquid Media. *Applied Physics A*. 110: 809-816.

[43] Rao, S. V., Podagatlapalli, G. K., Hamad, S. 2014. Ultrafast Laser Ablation in Liquids for Nanomaterials and Applications. *Journal of Nanoscience and Nanotechnology.* 14(2): 1364-1388.

[44] Valverde-Alva, M. A., García-Fernández, T., Villagrán-Muniz, M., Sánchez-Aké, C., Castañeda-Guzmán, R., Esparza-Alegría, E., Herrera, C. M. 2015. Synthesis of Silver Nanoparticles by Laser Ablation in Ethanol: A Pulsed Photoacoustic Study. *Applied Surface Science*. 355: 341-349.

[45] Dell'Aglio, M., Mangini, V., Valenza, G., De Pascale, O., De Stradis, A., Natile, G., De Giacomo, A. 2016. Silver and Gold Nanoparticles Produced by Pulsed Laser Ablation in Liquid to Investigate Their Interaction with Ubiquitin. *Applied Surface Science*: 374: 297-304.

[46] Resano-Garcia, A., Champmartin, S., Battie, Y., Koch, A., Naciri, A. E., Ambari, A., Chaoui, N. 2016. Highly-repeatable Generation of Very Small Nanoparticles by Pulsed-laser Ablation in Liquids of a High-speed Rotating Target. *Physical Chemistry Chemical Physics*.18: 32868-32875.

[47] Kohsakowski, S., Santagata, A., Dell'Aglio, M., de Giacomo, A., Barcikowski, S., Wagener, P., Gökce, B. 2017. High Productive and Continuous Nanoparticle Fabrication by Laser Ablation of a Wire-target in a Liquid Jet. *Applied Surface Science*. 403: 487-499.

[48] Grade, S., Eberhard, J., Wagener, P., Winkel, A., Sajti, C. L, Barcikowski, S., Stiesch, M. 2012. Therapeutic Window of Ligand-Free Silver Nanoparticles in Agar-Embedded and Colloidal State: In Vitro Bactericidal Effects and Cytotoxicity. *Advanced Engineering Materials*. 14: B231-B239.

[49] Pandey, J. K, Swarnkar, R. K., Soumya, K. K, Dwivedi, P., Singh, M. K., Sundaram, S., Gopal, R. 2014. Silver Nanoparticles Synthesized by Pulsed Laser Ablation: As a Potent Antibacterial Agent for Human Enteropathogenic Gram-positive and Gram-negative Bacterial Strains. *Applied Biochemistry and Biotechnology*. 174: 1021-1031.

[50] Korshed, P., Li, L., Liu, Z., Wang, T. 2016. The Molecular Mechanisms of the Antibacterial Effect of Picosecond Laser Generated Silver Nanoparticles and Their Toxicity to Human Cells. *PLoS One*. 11: e0160078.

[51] Fernández-Arias, M., Boutinguiza, M., del Val, J., Medina, E., Rodríguez, D., Riveiro, A., Pou, J. 2019. RE-irradiation of Silver Nanoparticles Obtained by Laser Ablation in Water and Assessment of Their Antibacterial Effect. *Applied Surface Science.* 473: 548-554.

[52] Ratti, M., Naddeo, J. J., Tan, Y., Griepenburg, J. C., Tomko, J., Trout, C., Klein, E. A. 2016. Irradiation with Visible Light Enhances the Antibacterial Toxicity of Silver Nanoparticles Produced by Laser Ablation. *Applied Physics A*. 122: 1-7.

[53] Baiee, R., Liu, Z., Li, L. 2019. Understanding the Stability and Durability of Laser-generated Ag Nanoparticles and Effects on Their Antibacterial Activities. *Advances in Natural Sciences: Nanoscience and Nanotechnology*. 10: 035001.

[54] Krce, L., Šprung, M., Maravić, A., Umek, P., Salamon, K., Krstulović, N., Aviani, I. 2020. Bacteria Exposed to Silver Nanoparticles Synthesized by Laser Ablation in Water: Modelling E. coli Growth and Inactivation. *Materials.* 13: 653.

[55] Sun Y., Xia Y. 2002. Shape-controlled Synthesis of Gold and Silver Nanoparticles. *Science.* 298: 2176-2179.

[56] Kim, D., Jeong S., Moon J. 2006. Synthesis of Silver Nanoparticles using the Polyol Process and the Influence of Precursor Injection. *Nanotechnology.* 17: 4019.

[57] Rozykulyyeva, L., Astuti, S. D, Zaidan, A. H., Pradhana, A. A. S., Puspita, P. S. 2020. Antibacterial Activities of Green Synthesized Silver Nanoparticles from Punica Granatum Peel Extract. *AIP Conference Proceedings* 2314. AIP Publishing.

[58] Chen, M., Feng, Y. G., Wang, X., Li, T. C., Zhang, J. Y., Qian D. J. 2007. Silver Nanoparticles Capped by Oleylamine: Formation, Growth, and Self-organization. *Langmuir*. 23: 5296-5304.

[59] Agnihotri, S., Mukherji, S., Mukherji, S. 2014 Size-controlled Silver Nanoparticles Synthesized over the Range 5–100 nm using the Same Protocol and Their Antibacterial Efficacy. *RSC Advances.* 4: 3974-3983.

[60] Li, W., Liu, Z., Fontana, F., Ding, Y., Liu, D., Hirvonen, J. T, Santos, H. A. 2018. Tailoring Porous Silicon for Biomedical Applications: From Drug Delivery to Cancer Immunotherapy. *Advanced Materials*. 30: 1703740.

[61] Sharma, G., Sharma, A. R., Kurian, M., Bhavesh R., Nam J. S., Lee, S. S. 2014. Green Synthesis of Silver Nanoparticle using Myristica Fragrans (nutmeg) Seed Extract and Its Biological Activity. *Digest Journal of Nanomaterials & Biostructures (DJNB)*. 9(1).

[62] Gurav, A. S, Kodas, T. T, Wang, L. M, Kauppinen, E. I, Joutsensaari, J. 1994. Generation of Nanometer-size Fullerene Particles via Vapor Condensation. *Chemical Physics Letters.* 218: 304-308.

[63] Jung, J. H., Oh, H. C., Noh, H. S, Ji., J. H., Kim, S. S. 2006. Metal Nanoparticle Generation using a Small Ceramic Heater with a Local Heating Area. *Journal of Aerosol Science*. 37(12): 1662-1670.

[64] Mafuné, F., Kohno, J. Y., Takeda, Y., Kondow T., Sawabe H. 2001. Formation of Gold Nanoparticles by Laser Ablation in Aqueous Solution of Surfactant. *The Journal of Physical Chemistry B.* 105: 5114-5120.

[65] Kabashin, A. V., Meunier, M. 2003. Synthesis of Colloidal Nanoparticles during Femtosecond Laser Ablation of Gold in Water. *Journal of Applied Physics.* 94: 7941-7943.

[66] Hwang, C. B, Fu, Y. S, Lu, Y. L, Jang, S. W, Chou, P. T, Wang, C. C, Yu, S. J. 2000. Synthesis, Characterization, and Highly Efficient Catalytic Reactivity of Suspended Palladium Nanoparticles. *Journal of Catalysis.* 195: 336-341.

[67] Semerok, A. F., Chaleard, C., Detalle, V., Kocon, S., Lacour, J. L., Mauchien, P., Salle, B. 1998. Laser Ablation Efficiency of Pure Metals with Femtosecond, Picosecond, and Nanosecond Pulses. *High-Power Laser Ablation.* 3343: 1049-1055. SPIE.

[68] Becker, M. F, Brock, J. R., Cai, H., Henneke, D. E., Keto, J. W., Lee, J., Glicksman, H. D. 1998. Metal Nanoparticles Generated by Laser Ablation. *Nanostructured Materials.* 10: 853-863.

[69] Kazakevich, P. V., Simakin, A. V., Shafeev, G. A., Monteverde, F., Wautelet, M. 2007. Phase Diagrams of Laser-processed Nanoparticles of Brass. *Applied Surface Science*. 253: 7724-7728.

[70] Mahfouz, R. M., Al-Khamis, K. M., Siddiqui, M. R. H., Al-Hokbany, N. S., Warad, I., Al-Andis, N. M. 2012. Kinetic Studies of Isothermal Decomposition of Unirradiated and γ-irradiated Gallium Acetylacetonate: New Route for Synthesis of Gallium Oxide Nanoparticles. *Progress in Reaction Kinetics and Mechanism.* 37: 249-262.

[71] Mafuné, F., Kohno, J. Y., Takeda, Y., Kondow, T., Sawabe, H. 2000. Structure and Stability of Silver Nanoparticles in Aqueous Solution Produced by Laser Ablation. *The Journal of Physical Chemistry B*. 104: 8333-8337.

[72] TSUJI, T., USUKURA, J. 2012. Assessment on a Biological Toxicity Caused by Single-walled Carbon Nanotubes. *Nano Biomedicine.* 4: 125-132.

[73] Kumar Ghosh, S., Kundu, S., Mandal, M., Nath, S., Pal, T. 2003. Studies on the Evolution of Silver Nanoparticles in Micelle by UV-photoactivation. *Journal of Nanoparticle Research.* 5: 577-587.

[74] Iravani, S., Korbekandi, H., Mirmohammadi, S. V., Zolfaghari, ,B. 2014. Synthesis of Silver Nanoparticles: Chemical, Physical and Biological Methods. *Research in Pharmaceutical Sciences.* 9(6): 385.

[75] Huang, L., Zhai, M. L, Long, D. W, Peng, J., Xu, L., Wu, G. Z, Wei, G. S. 2008. UV-induced Synthesis Characterization and Formation Mechanism of Silver Nanoparticles in Alkalic Carboxymethylated Chitosan Solution. *Journal of Nanoparticle Research.* 10: 1193-1202.

[76] Balan, L., Schneider, R., Turck, C., Lougnot, D., Morlet-Savary, F. 2012. Photogenerating Silver Nanoparticles and Polymer Nanocomposites by Direct Activation in the Near Infrared. *Journal of Nanomaterials*. 2012: 1-1.

[77] Sakamoto, M., Fujistuka, M., Majima, T. 2009. Light as a Construction Tool of Metal Nanoparticles: Synthesis and Mechanism. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews.* 10: 33-56.

[78] Sintubin, L., Verstraete, W., Boon, N. 2012. Biologically Produced Nanosilver: Current State and Future Perspectives. *Biotechnology and Bioengineering*. 109: 2422-2436.

[79] Suresh, A. K., Pelletier, D. A., Wang, W., Moon, J. W., Gu, B., Mortensen, N. P., Doktycz, M. J. 2010. Silver Nanocrystallites: Biofabrication using Shewanella Oneidensis, and an Evaluation of their Comparative Toxicity on Gram-negative and Gram-positive Bacteria. *Environmental Science & Technology.* 44: 5210-5215.

[80] Fayaz, A. M., Balaji, K., Girilal, M., Yadav, R., Kalaichelvan, P. T., Venketesan, R. 2010. Biogenic Synthesis of Silver Nanoparticles and Their Synergistic Effect with Antibiotics: A Study against Gram-positive and Gram-negative Bacteria. *Nanomedicine: Nanotechnology, Biology and Medicine*. 6: 103-109.

[81] Thirumalai Arasu, V., Prabhu, D., Soniya, M. 2010. Stable Silver Nanoparticle Synthesizing Methods and Its Applications. *J. Bio. Sci. Res*. 1: 259-270.

[82] Pugazhenthiran, N., Anandan, S., Kathiravan, G., Udaya Prakash, N. K, Crawford, S., Ashokkumar, M. 2009. Microbial Synthesis of Silver Nanoparticles by Bacillus sp. *Journal of Nanoparticle Research*. 11: 1811-1815.

[83] Haider, A., Kang, I. K. 2015. Preparation Of Silver Nanoparticles and Their Industrial and Biomedical Applications: A Comprehensive Review. *Advances in Materials Science and Engineering*. 1-16.

[84] Yaqubi, A. K, Astuti, S. D, Permatasari, P. A. D, Komariyah, N., Endarko, E., Zaidan, A. H. 2022. In Vitro Inactivation Efficiency of Bacillus Subtilis and Escherichia Coli Bacteria in Sterilizers using Violet Irradiation. *Biomedical Photonics*. 11: 4-10.

[85] Permatasari, P. A. D., Astuti, S. D., Yaqubi, A. K, Paisei, E. A. W, Anuar, N. 2023. Antibacterial Efficacy of Chlorophyll from Katuk (Sauropus androgynus (L) Merr) Leaves with Blue and Red Laser Activation against the Biofilm of Aggregatibacter Actinomycetemcomitans and Enterococcus Faecalis. *Biomedical Photonics.* 12: 14-21

[86] Wang, J. X., Wen, L. X., Wang, Z. H., Chen, J. F. 2006. Immobilization of Silver on Hollow Silica Nanospheres and Nanotubes and Their Antibacterial Effects. *Materials Chemistry and Physics.* 96: 90-97.

[87] Bosetti, M., Bianchi, A. E, Zaffe, D., Cannas, M. 2013. Comparative in Vitro Study of Four Commercial Biomaterials used for Bone Grafting. *Journal of Applied Biomaterials & Functional Materials.* 11: 80-88.

[88] Choi, Y., Jeon, D., Choi, Y., Ryu, J., Kim, B. S. 2018. Self-assembled Supramolecular Hybrid of Carbon Nanodots and Polyoxometalates for Visible-light-driven Water Oxidation. *ACS Applied Materials & Interfaces*. 10: 13434-13441.

[89] Yeo, S., Lee, T. H., Kim, M. J., Shim, Y. K., Yoon, I., Song, Y. K, Lee, W. K. 2023. Improved Anticancer Efficacy of Methyl Pyropheophorbide-a–incorporated Solid Lipid Nanoparticles in Photodynamic Therapy. *Scientific Reports* 13: 7391.

[90] Duran, N., Simoes, M. B., de Moraes, A., Favaro, W. J, Seabra, A. B. 2016. Nanobiotechnology of Carbon Dots: A Review. *Journal of Biomedical Nanotechnology*. 12: 1323-1347.

[91] Hahm, J. I., Lieber, C. M. 2004. Direct Ultrasensitive Electrical Detection of DNA and DNA Sequence Variations using Nanowire Nanosensors. *Nano Letters*. 4: 51-54.

[92] Köhler, J. M, Held, M., Hübner, U., Wagner, J. 2007. Formation of Au/Ag Nanoparticles in a Two Step Micro Flow-Through Process. Chemical Engineering & Technology: *Industrial Chemistry*‐*Plant Equipment*‐*Process Engineering*‐*Biotechnology*. 30: 347-354.

[93] Guo, J., Tang, J., Wang, J., Mao, S., Li, H., Wang, Y., Belfiore, L. A. 2018. Europium (III)-induced Water-soluble Nano-aggregates of Hyaluronic Acid and Chitosan: Structure and Fluorescence. *MRS Communications*. 8: 1224-1229.

[94] Berciaud, S., Li, X., Htoon, H., Brus, L. E., Doorn, S. K, Heinz, T. F. 2013. Intrinsic Line Shape of the Raman 2D-mode in Freestanding Graphene Monolayers. *Nano Letters*. 13: 3517-3523.

[95] El-Sayed, M., Masuhara, H., Pileni, M. P., Landes, C. 2012. Nano and Molecular Science and Technology Special Issue Honoring Paul Barbara. *Accounts of Chemical Research*. 45: 1842-1843.

[96] Haider, A., Kang, I. K. 2015. Preparation of Silver Nanoparticles and Their Industrial and Biomedical Applications: A Comprehensive Review. *Advances in Materials Science and Engineering*. 1-16.

[97] Dakal, T. C., Kumar, A., Majumdar, R. S., Yadav, V. 2016. Mechanistic Basis of Antimicrobial Actions of Silver Nanoparticles. *Frontiers in Microbiology*. 7: 1831.

[98] Suhariningsih, Dwi, W., Husen, S. A., Firas, K., Pramudita, P. A., & Astuti, S. D. 2020. The Effect of Electric Field, Magnetic Field, and Infrared Ray Combination to Reduce HOMA-IR Index and GLUT 4 in Diabetic Model of Mus Musculus. *Lasers in Medical Science*. *35*(6): 1315-1321.

[99] Ivask, A., ElBadawy, A., Kaweeteerawat, C., Boren, D., Fischer, H., Ji, Z., Godwin, H. A. 2014. Toxicity Mechanisms in Escherichia coli Vary for Silver Nanoparticles and Differ from Ionic Silver. *ACS Nano*. 8: 374-386.

[100] Seil, J. T., Webster, T. J. 2012. Antimicrobial Applications of Nanotechnology: Methods and Literature. *International Journal of Nanomedicine*. 2767-2781.

[101] Li, W. R, Xie, X. B., Shi, Q. S, Zeng, H. Y., Ou-Yang, Y. S., Chen, Y. B. 2010. Antibacterial Activity and Mechanism of Silver Nanoparticles on Escherichia coli. *Applied Microbiology and Biotechnology*. 85: 1115-1122.

[102] Gomaa, E. Z. 2017. Silver Nanoparticles as an Antimicrobial Agent: A Case Study on Staphylococcus aureus and Escherichia coli as Models for Gram-positive and Gram-negative Bacteria. *The Journal of General and Applied Microbiology*. 63: 36-43.

[103] Lu, Z., Rong, K., Li, J., Yang, H., Chen, R. 2013. Size-dependent Antibacterial Activities of Silver Nanoparticles Against Oral Anaerobic Pathogenic Bacteria. *Journal of Materials Science*: *Materials in Medicine*. 24: 1465-1471.

[104] Agnihotri, S., Mukherji, S., Mukherji, S. 2014. Size-controlled Silver Nanoparticles Synthesized over the Range 5–100 nm using the Same Protocol and Their Antibacterial Efficacy. *RSC Advances*. 4: 3974-3983.

[105] Astuti, S. D., Victory, V. S., Mahmud, A. F., Putra, A. P., & Winarni, D. 2019. The Effects of Laser Diode Treatment on Liver Dysfunction of Mus Musculus Due to Carbofuran Exposure: An In Vivo Study. *Journal of Advanced Veterinary and Animal Research*. 6(4): 499.

[106] Lansdown, A. B. 2004. A Review of the Use of Silver in Wound Care: Facts and Fallacies. *British Journal of Nursing*. 13: S6-S19.

[107] Feng, Q. L., Wu, J., Chen, G. Q., Cui, F.Z., Kim, T. N., Kim, J. O. 2000. A Mechanistic Study of the Antibacterial Effect of Silver Ions on Escherichia coli and Staphylococcus aureus. *Journal of Biomedical Materials Research*. 52: 662-668.

[108] Wong, K. K., Liu, X. 2010. Silver Nanoparticles the Real "Silver Bullet" in Clinical Medicine? *MedChemComm*. 1: 125-131.

[109] Ul-Islam, M., Shehzad, A., Khan, S., Khattak, W. A, Ullah, M. W., Par, k J. K. 2014. Antimicrobial and Biocompatible Properties of Nanomaterials. *Journal of Nanoscience and Nnanotechnology*. 14: 780-791.

[110] Sunarko, S. A., Ekasari, W., Astuti, S. D. 2017. Antimicrobial Effect of Pleomeleangustifolia Pheophytin A Activation with Diode Laser to Streptococcus Mutans. *Journal of Physics: Conference Series*. 853: 012039. IOP Publishing.

[111] Marambio-Jones, C., Hoek, E. M. 2010. A Review of the Antibacterial Effects of Silver Nanomaterials and Potential Implications for Human Health and the Environment. *Journal of Nanoparticle Research*. 12: 1531-1551.

[112] Sondi, I., Salopek-Sondi, B. 2004. Silver Nanoparticles as Antimicrobial Agent: A Case Study on E. coli as a Model for Gram-negative Bacteria. *Journal of Colloid and Interface Science*. 275: 177-182.

[113] Shrivastava, S., Bera, T., Roy, A., Singh, G., Ramachandrarao, P., Dash, D. 2007. Characterization of Enhanced Antibacterial Effects of Novel Silver Nanoparticles. *Nanotechnology*. 18: 225103.

[114] Pal, S., Tak, Y. K., Song, J. M. 2007. Does the Antibacterial Activity of Silver Nanoparticles Depend on the Shape of the Nanoparticle? A Study of the Gram-negative Bacterium Escherichia coli. *Applied and Environmental Microbiology*. 73: 1712-1720.

[115] Enoch, D. A., Ludlam, H. A., Brown, N. M. 2006. Invasive Fungal Infections: A Review of Epidemiology and Management Options. *Journal of Medical Microbiology*. 55: 809-818.

[116] Guo, T., Nikolaev, P., Rinzler, A. G., Tomanek, D., Colbert, D. Smalley, R. E. 1995. Self-assembly of Tubular Fullerenes. *The Journal of Physical Chemistry*. 99: 10694-10697.

[117] Guo, T., Nikolaev, P., Thess, A., Colbert, D. T., Smalley, R. E. 1995. Catalytic Growth of Single-walled Manotubes by Laser Vaporization. *Chemical Physics Letters*. 243: 49-54.

[118] Eason, R. 2007. *Pulsed Laser Deposition of Thin Films: Applications-Led Growth of Functional Materials*. John Wiley & Sons.

[119] Grant-Jacob, J. A., Beecher, S. J., Parsonage, T. L., Hua, P., Mackenzie, J. I., Shepherd, D. P., Eason, R. W. 2016. An 11.5 W Yb: YAG Planar Waveguide Laser Fabricated via Pulsed Laser Deposition. *Optical Materials Express*. 6: 91-96.

[120] Zheng, W., Lee, J., Gao, Z. W., Li, Y., Lin, S., Lau, S. P., Lee, L. Y. S. 2020. Laser-assisted Ultrafast Exfoliation of Black Phosphorus in Liquid with Tunable Thickness for Li-ion Batteries. *Advanced Energy Materials*. 10: 1903490.

[121] Astuti, S. D., Sulistyo, A., Setiawatie, E. M., Khasanah, M., Purnobasuki, H., Arifianto, D., ... & Syahrom, A. 2021. An In-vivo Study of Photobiomodulation using 403 nm and 649 nm Diode Lasers for Molar Tooth Extraction Wound Healing in Wistar Rats. *Odontology*. 1-14.

[122] Astuti, S. D., Widya, I. W., Arifianto, D., & Apsari, R. 2019. Effectiveness Photodynamic Inactivation with Wide Spectrum Range of Diode Laser to Staphylococcus aureus Bacteria with Endogenous Photosensitizer: An in vitro Study. *Journal of International Dental and Medical Research*. 12(2): 481-486.

[123] Orellana, F. A., Gálvez, C. G., Roldán, M. T., García-Ruiz, C. 2013. Applications of Laser-ablation-inductively-coupled Plasma-mass Spectrometry in Chemical Analysis of Forensic Evidence. *TrAC Trends in Analytical Chemistry*. 42: 1-34.

[124] Urgast, D. S., Beattie, J. H., Feldmann, J. 2014. Imaging of Trace Elements in Tissues: With a Focus on Laser Ablation

Inductively Coupled Plasma Mass Spectrometry. *Current Opinion in Clinical Nutrition & Metabolic Care*. 17: 431-439.

[125] Pozebon, D., Scheffler, G. L., Dressler, V. L., Nunes, M. A. 2014. Review of the Applications of Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) to the Analysis of Biological Samples. *Journal of Analytical Atomic Spectrometry*. 29: 2204-2228.

[126] Kuang, S., Doran, S. A., Wilson, R. J., Goss, G. G., Goldberg, JI. 2002. Serotonergic Sensory-motor Neurons Mediate a Behavioral Response to Hypoxia in Pond Snail Embryos. *Journal of Neurobiology*. 52: 73-83.

[127] Jékely, G., Colombelli, J., Hausen, H., Guy, K., Stelzer, E., Nédélec, F., Arendt, D. 2008. Mechanism of Phototaxis in Marine Zooplankton. *Nature*. 456: 395-399.

[128] Neddersen, J., Chumanov, G., Cotton, T. M. 1993. Laser Ablation of Metals: A New Method for Preparing SERS Active Colloids. *Applied Spectroscopy*. 47(12): 1959-1964.

[129] Dolgaev, S. I., Simakin, A. V., Voronov, V. V., Shafeev, G. A., Bozon-Verduraz, F. 2002. Nanoparticles Produced by Laser Ablation of Solids in Liquid Environment. *Applied Surface Science*. 186: 546-551.

[130] Boutinguiza, M., Rodríguez-González, B., Del Val, J., Comesaña, R., Lusquiños, F., Pou, J. 2011. Laser-assisted Production of Spherical TiO_2 Nanoparticles in Water. *Nanotechnology*. 22: 195606.

[131] Amendola, V., Meneghetti, M. 2009. Laser Ablation Synthesis in Solution and Size Manipulation of Noble Metal Nanoparticles. *Physical Chemistry Chemical Physics*. 11: 3805-3821.

[132] Amendola, V., Meneghetti, M. 2013. What Controls the Composition and the Structure of Nanomaterials Generated by Laser Ablation in Liquid Solution? *Physical Chemistry Chemical Physics.* 15: 3027-3046.

[133] Barcikowski, S., Compagnini, G. 2013. Advanced Nanoparticle Generation and Excitation by Lasers in Liquids. *Physical Chemistry Chemical Physics*. 15: 3022-3026.

[134] Wagener, P., Jakobi, J., Rehbock, C., Chakravadhanula, V. S. K., Thede, C., Wiedwald, U., Barcikowski, S. 2016. Solvent-surface Interactions Control the Phase Structure in Laser-generated Iron-gold Core-shell Nanoparticles. *Scientific Reports*. 6: 23352.

[135] Fazio, E., Gökce, B., De Giacomo, A., Meneghetti, M., Compagnini, G., Tommasini, M., Neri, F. 2020. Nanoparticles Engineering by Pulsed Laser Ablation in Liquids: Concepts and Applications. *Nanomaterials*. 10: 2317.

[136] Rehbock, C., Merk, V., Gamrad, L., Streubel R, Barcikowski S. 2013. Size Control of Laser-fabricated Surfactant-free Gold Nanoparticles with Highly Diluted Electrolytes and Their Subsequent Bioconjugation. *Physical Chemistry Chemical Physics.* 15: 3057-3067.

[137] Barcikowski S, Menéndez-Manjón A, Chichkov B, Brikas M, Račiukaitis G. 2007. Generation of Nanoparticle Colloids by Picosecond and Femtosecond Laser Ablations in Liquid Flow. *Applied Physics Letters*. 91.

[138] Xu, B., Song, R. G. 2010. Fabrication of Ag Nanoparticles Colloids by Pulsed Laser Ablation in Liquid. *Advanced Materials Research.* 123: 675-678.

[139] Mendivil, M. I., Krishnan, B., Sanche, F. A., Martinez, S, Aguilar-Martinez, J. A., Castillo, G. A., Shaji, S. 2013. Synthesis of Silver Nanoparticles and Antimony Oxide Nanocrystals by Pulsed Laser Ablation in Liquid Media. *Applied Physics A.* 110: 809-816.

[140] Resano-Garcia, A., Champmartin, S., Battie, Y., Koch, A., Naciri, A. E., Ambari, A., Chaoui, N. 2016. Highly-repeatable Generation of Very Small Nanoparticles by Pulsed-laser Ablation in Liquids of a High-speed Rotating Target. *Physical Chemistry Chemical Physics*. 18: 32868-32875.

[141] Kohsakowski, S., Santagata, A., Dell'Aglio, M., de Giacomo, A., Barcikowski, S., Wagener, P., Gökce, B. 2017. High Productive and Continuous Nanoparticle Fabrication by Laser Ablation of a Wire-Target in a Liquid Jet. *Applied Surface Science*. 403: 487-499.

[142] Grade, S., Eberhard, J., Wagener, P., Winkel, A., Sajti, C. L., Barcikowski, S., Stiesch, M. 2012. Therapeutic Window of Ligand-Free Silver Nanoparticles in Agar-Embedded and Colloidal State: In Vitro Bactericidal Effects and Cytotoxicity. *Advanced Engineering Materials*. 14: B231-B239.

[143] Pandey, J. K., Swarnkar, R. K., Soumya, K. K., Dwivedi, P., Singhm M. K., Sundaram, S., Gopal, R. 2014. Silver Nanoparticles Synthesized by Pulsed Laser Ablation: As a Potent Antibacterial Agent for Human Enteropathogenic Gram-positive and Gram-negative Bacterial Strains. *Applied biochemistry and biotechnology*. 174: 1021-1031.

[144] Menazea, A. A. 2020. Femtosecond Laser Ablation-assisted Synthesis of Silver Nanoparticles in Organic and Inorganic Liquids Medium and Their Antibacterial Efficiency. *Radiation Physics and Chemistry*. 168: 108616.

[145] Astuti, S. D., Prasaja, B. I., & Prijo, T. A. 2017. An in Vivo Photodynamic Therapy with Diode Laser to Cell Activation of Kidney Dysfunction. *Journal of Physics: Conference Series.* IOP Publishing. 853(1): 012038.

[146] Astuti, S. D., Zaidan, A., Setiawati, E. M., Suhariningsih, S. 2016. Chlorophyll Mediated Photodynamic Inactivation of Blue Laser on Streptococcus Mutans. *AIP Conference Proceedings*. 1718(1). AIP Publishing.

[147] Baiee, R., Liu, Z., Li, L. 2019. Understanding the Stability and Durability of Laser-generated Ag Nanoparticles and Effects on Their Antibacterial Activities. *Advances in Natural Sciences: Nanoscience and Nanotechnology*. 10: 035001.

[148] Krce, L., Šprung, M., Maravić, A., Umek, P., Salamon, K., Krstulović, N., Aviani, I. 2020. Bacteria Exposed to Silver Nanoparticles Synthesized by Laser Ablation in water: Modelling E. coli Growth and Inactivation. *Materials*. 13: 653.