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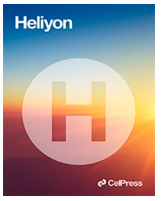

Research article

Antimicrobial coating of biologically synthesized silver nanoparticles on surgical fabric and surgical blade to prevent nosocomial infections

Ifrah Tahir [a], Sundus Jabeen Amina [a], Nasir Mahmood Ahmed [b], Hussnain Ahmad Janjua [a,*]

[a] Department of Industrial Biotechnology, Atta–ur-Rahman School of Applied Biosciences, National University of Sciences and Technology (NUST), Islamabad, 44000, Pakistan
[b] Department of Chemical Engineering, School of Chemical & Materials Engineering, NUST, Islamabad, 44000, Pakistan

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ABSTRACT

In this study, biologically synthesized AgNPs were found to be effective against six hospital prevalent bacterial species (*Pseudomonas aeruginosa*, *Escherichia coli, Acinetobacter baumannii*, *Klebsiella pneumoniae*, Methicillin-resistant *Staphylococcus aureus* and *Enterococcus faecalis*). AgNPs were deposited on the fabric and surgical blades using layer-by-layer and electrochemical deposition methods, respectively. The coated objects were characterized using scanning electron microscopy, X-ray diffraction and Fourier transform infrared spectroscopy and energy dispersive X-ray. Coated fabric samples and blades when tested against six above mentioned bacterial species were found to be effective for all of them. Antibiofilm activity of AgNPs coated blade and fabric was tested against *P. aeruginosa* and SEM images of post-treated fabrics and blades showed clear bacterial cell distortion and inhibition. Furthermore, washing durability test revealed that AgNPs were strongly attached to the surface of fabric even after 20 cycles of hospital laundering. This unlocks the way to several technologically relevant applications of AgNPs coated surfaces to reduce the risks of nosocomial infections and as a proof of concept; we demonstrated efficient antibacterial properties of AgNPs coated cotton fabric and surgical blades.

1. Introduction

Nosocomial infections are mostly known as hospital acquired infections (HCAIs) which occur in hospitals/aclinical settings and are caused by number of agents, most commonly bacteria, viruses and fungal parasites [1]. To minimize the incidences of nosocomial infections and to significantly decrease mortality and morbidity rates several advanced strategies are developed. Conventional methods employed in reducing these infections include, cleaning and the use disinfectants. With the major breakthroughs in the field of

Abbreviations: mg, Microgram; nm, Nanometer; ml, Millilitre; mg, Milligram; mM, Millimolar; rpm, Rotations Per Minute; CFU, Colony Forming Unit; $AgNO_3$, Silver Nitrate; PDAC, Polydiallyldimethyl ammonium chloride; OM, Optical Microscopy; OP, Optical Profilometry; SEM, Scanning Electron Microscopy; EDX, Energy Dispersive X-Ray; XRD, X-Ray Diffraction; FTIR, Fourier Transmission Infrared spectroscopy; MRSA, Multiple Drug Resistant Staphylococcus Aureus; LB, Luria Bertani; TSB, Tryptone Soya Broth; PBS, Phosphate Buffer Saline.

* Corresponding author.
E-mail addresses: janjua.hussnain@gmail.com, hussnain.janjua@asab.nust.edu.pk (H.A. Janjua).

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nanotechnology, metal nanoparticles, particularly silver nanoparticles (AgNPs), owing to their antimicrobial properties against many harmful microbes have revolutionized artificial implantations [2] and wound dressings [3] for the prevention of postsurgical contamination caused by microbial organisms. Release of Ag^{+} ions from silver nanoparticles makes them good antibacterial agent. Sondi et al. demonstrated in previous study that silver nanoparticles penetrate the cell membrane of *E. coli* resulting in the increase in its permeability thus, leading to the cell death [4].

Antimicrobial effect of silver nanoparticles is proven in wound healing including surgical and burn wounds and ulcers [5], prevention of severe infectious diseases [6] and water sterility [7]. Previous study has demonstrated that multi-drug resistant bacteria such as *E. coli*, *K. pneumoniae* and *P. aeruginosa* showed reduction in their activity when are in-contact with silver nanoparticles synthesized from cell free supernatants of *A. baumannii* [8]. Moreover, the effect of silver nanoparticles on leg ulcers was studied by Miller during a randomized-controlled trial. The results provided evidence that silver coating helps in healing older and larger ulcers [9]. In wound dressings, silver nanoparticles are applied on burn injuries [10], open wounds and fractures [11,12]. Moreover, silver nanoparticle coated threads were utilized to stitch wounds thus preventing infections from spreading [13]. Nano-silver finished fabric possesses antibacterial activities with potential applications in hospitals and clinical settings as bed sheet covers, curtains, medical practitioner's coats [14]. The use of AgNp in textile production can lead to the creation of textiles with entirely new properties and the integration of multiple functions. Such multifunctional textiles include antistatic textiles, reinforced textiles, antibacterial, self-cleaning textiles, bleaching resistant textiles, etc.

For the surface modification of fabric with nanoparticles, various methods such as screen printing, padding squeezing, spray, sonochemical, and dip coating are most commonly used. For enhancing the adsorption and stability of nanoparticles on fabric, various binding chemicals have been used in the coating process. Past researches have shown layer-by-layer coating of fabric with chemicals and enzymes to impart UV blocking, flame retardant, anti-wetting and antibacterial properties to the fabric but there are only few studies which have used layer-by-layer method for coating of nanoparticles on cotton fabric which is the most commonly used fabric in hospital settings. A previous study has elaborated the used layer-by-layer method for depositing silver nanoparticles on silk and nylon fabric in which fabric was dipped in PDADMAC (polydiallyldimethylammonium chloride) solution for 5 min followed by two successive washing steps and subsquentlydipped in PMA capped silver nanoparticles solution for 5 min followed by two washing steps [15]. Silver finished fabric showed good antibacterial activity against *S. aureus*. In another study Ugur et al. developed nanocomposite film on the surface of fabric using zinc oxide nanoparticles. Antibacterial testing revealed that coated fabric exhibits efficient antibacterial activity against *S. aureus* [16]. In the current study, layer-by-layer method was applied for coating silver nanoparticles on cotton fabric. PDAC (poly diallyldimethyl ammonium chloride) was used as cationic solution whereas; silver nanoparticles were utilized as anionic solution.

Similarly, very limited data is available showing the application of AgNPs in coating of surgical blades to impart antibacterial properties to them to avoid cross-contamination during surgical procedures. Previously, electrochemical deposition method has been shown to evenly decorate AgNPs on surface of substrate. This technique produces apparently uniform and reproducible multilayer coatings of nanoparticles on substrate. In one study metallic nanoparticles were electrochemically deposited on carbon nano-tubes [17]. Another study reported electro-deposition of copper-nickel-iron nanoparticles on stainless steel in which stainless-steel plate was cut in dimensions of approximately 50 mm $\times$ 15 mm x 10 mm. Pre-treatment of stainless-steel plate was performed by polishing it using emery paper. Stainless steel was used as cathode whereas, graphite was used as anode. The parameter settings for this experiment included; fixed pH at 3 by adding HNO_3, 323K temperature, current range between 0.143 A/cm^2 to 0.145 A/cm^2 and the deposition times of 30, 60 and 90 min [18].

Current research focuses on antibacterial coating of biologically synthesized silver nanoparticles on surgical fabric and surgical blades using layer-by-layer deposition and electrochemical deposition methods, respectively. Antibacterial effects of coated surgical fabric and surgical blade were tested against six major pathogenic bacterial species that cause nosocomial infection. This study provides reliable product in the form of nano-fabric to minimize the chances of nosocomial infections.

2. Materials and methods

2.1. Antibacterial activity of silver nanoparticles

2.1.1. Collection of bacterial strains, preparation of concentrations of AgNPs and McFarland standard

Six pathogenic bacterial strains were collected from Armed Forces Institute of Pathology, Combined Military Hospital (C.M.H) Rawalpindi, Pakistan. These included both gram negative (*P. aeruginosa*, *A. baumannii*, *K. pneumoniae*, *E. coli*) and gram positive (*S. aureus*, *E. faecalis*) bacteria. Each of the samples was treated according to the standard protocol followed by AFIP. Specimens were streaked on nutrient agar and allowed to incubate at 37 °C overnight which were then added in glycerol stock solution of 87 % and stored at −80 °C.

Concentrations of silver nanoparticles synthesized from *Aerva javanica* plant using previously described method by Hashmi et al. were prepared to test their antimicrobial activity [19]. Silver nanoparticles were prepared by mixing plant extract and silver nitrate. For the synthesis of AgNPs, 10 mL of 100 mg/mL concentration of plant solution mixed with100mL of 1 mM silver nitrate solution in a ratio of 1:10. Prepared AgNP were then lyophilized and converted into powdered form. In order To make different concentrations of AgNPs (0.25 mg/ml, 0.5 mg/ml, 1.0 mg/ml, 1.5 mg/ml and 2.0 mg/ml) required amount of powdered AgNP was weighed and added in deionized water by continuous vortexing at high resolution, accompanied with sonication of 1 h before use.

For comparing the turbidity of bacterial cultures in disk diffusion assay 0.5 Mc Farland was used, 0.05 ml of 1.17 % barium chloride dihydrate ($BaCl_2.2H_2O$) was mixed with 9.95 ml of 1 % of sulphuric acid (H_2SO_4). The absorbance of 0.9 was determined using

spectrophotometer for prepared standard. Reaction mixture was sealed in test tube and stored in dark util further usage.

2.1.2. Antibacterial disk diffusion assay

Nutrient agar pleases were used for disk diffusion assay, 0.9 % of normal saline was made by mixing 0.9g of sodium chloride in 100 ml of distilled water and autoclaved before use, 5 ml of normal saline was added in sterile test tube in the laminar flow hood. Using sterile loop microbial colonies were picked from 16 h cultured plates and released into the normal saline and the turbidity was comparable to 0.5 Mc Farland standard. With 300 μl of microbial inoculum in normal saline pipetted out and dropped on to the nutrient agar plate, he Sterilized spreader was then used to spread bacterial inoculum evenly throughout the plate. Sterile filter paper discs made from Whatman filter paper were fixed on inoculated plates with the help of sterile syringe. Different concentrations of silver nanoparticles (0.25, 0.5, 1.0, 1.5 and 2.0 mg/ml) were added to filter paper discs. As a negative control, deionized water was used. Plates were incubated overnight at 37 °C.

2.2. Coating of silver nanoparticles on surgical fabric

2.2.1. Preparation of PDAC

PDAC (poly diallyldimethyl ammonium chloride) is a light-yellow viscose cationic solution. For layer-by-layer coating, 0.016 % PDAC solution was prepared by dissolving 0.8 ml of PDAC polymer in 100 ml of de-ionized water to prepare final solution of 0.016 %.

2.2.2. Pre-treatment of surgical fabric

Cotton fabric was selected as a textile substrate because of its wide use in hospital and clinical settings. The fabric swatches were cut in the dimensions of 5cm × 3 cm,washed to remove any adhered impurities and then dried at ambient conditions and stored at 4 °C.

2.2.3. Layer-by-layer deposition of AgNPs on surgical fabric

Silver nanoparticles solution (50 ml of 1 mM) was made and utilized as anionic solution in current method. A layer-by-layer assemblage was set-up that a fabric swatch dipped in PDAC solution for 10 min followed by 2 successive washing steps in distilled water each for 5 min [15]. The fabric was then dipped in AgNPs solution for 10 min followed by 2 further washing steps. This method leads to the formulation of a single layer in a period of 40 min. Whole procedure was repeated to produce samples with 5, 10, 25, 15 and 20 layers. At room temperature fabric swatches were dried for 3–4 h and stored in moisture free environment.

2.3. Coating of silver nanoparticles on surgical blade

2.3.1. Pretreatment of surgical blade

Stainless steel surgical blades No. 24 (6 mm in diameter and approximately 3 mm in height) were selected and purchased from a local pharmacy because of their excessive utility in surgical operations. Prior to electrochemical deposition, blades were dressed by ultra-sonication for 15 min each in acetone, ethanol & de-ionized water sequentially. Cleaned and sterilized surgical blades were then used as a substrate for deposition with silver nanoparticles.

2.3.2. Electrochemical deposition of AgNPs on surgical blade

Two electrodes system was used with surgical blades serving as anode and platinum wire acting as cathode. The pH value and voltage were set at 5.1 and 3V, respectively [20]. with 1 mM of silver nanoparticles used as electrolyte and nearly 1 cm of the blade and platinum wire was hanged in 80 ml of silver nanoparticles solution. The space among each electrode was around 1 cm. A power source applied a dc voltage for 20 min. All the measurements were applied at room temperature without de-aeration of the solution. After deposition blades were rinsed extensively with ultrapure water and kept at room temperature.

2.4. Characterization of coated objects

2.4.1. Optical microscopy (OM)

Coated fabrics were observed under optical microscope (Optika B-600 MET) at different magnifications (5x, 10x, 20x and 50x) to check the presence of silver nanoparticles on the samples and to determine the difference between the samples having different number of layers. The uncoated fabric sample was also observed as a control under optical microscope for comparative analysis.

2.4.2. Optical profilometry (OP)

Optical profilometry was performed to determine the average roughness (nm) of coated and uncoated fabric samples. The fabric swatches were cut into small sections and fixed onto the glass slides using paper clips. The prepared sample was then analyzed using Nanovea PS-50 optical profilometry instrument.

2.4.3. Scanning electron microscope (SEM) and energy dispersive X-ray (EDX)

SEM (JSM 6490LA, JEOL microscope, Japan) was used to analyze surface morphology of silver nanoparticles coated fabric swatches and blades. Samples were prepared by fixing specimens of fabrics and blades onto the glass slide using double tape. These samples were gold coated with an Auto-fine coater (JEOL, Japan) in order to avoid charge effect. Surface morphologies of the samples were imaged at different magnifications. EDX analysis was performed to assess the distribution of AgNPs on fabric and blade surface.

2.4.4. Fourier transform infrared spectroscopy (FTIR)

FTIR spectroscopy analysis was carried out to investigate chemical composition of silver nanoparticles coated samples. Prior to any measurement, fabric swatches were kept at room temperature for 2 h whereas; blade samples were eroded with methanol and further dried at 50 °C for 30 min. The spectra of coated fabric and blade were obtained in the range of 4500–500 cm^{-1}.

2.4.5. X-ray diffraction (XRD)

XRD analysis was performed to assess the crystalline and amorphous nature of coated samples. Peaks of XRD provided the confirmation of coating of AgNPs on the samples surface. Intensity of the diffraction peaks was directly linked to the amount of silver content present on the samples. Samples were prepared by fixing fabric swatches and blades onto the glass slide using tape and were subsquently analyzed at voltage 20 kV with current set at 5 mA.

2.5. Antibacterial activity of coated objects

2.5.1. Preparation of bacterial cultures and media

P. aeruginosa, *E. coli*, *A. baumannii*, *K. pneumoniae*, *S. aureus* and *E. faecalis* were obtained from AFIP as mentioned above. These species were selected for carrying out antibacterial activity of coated surgical fabric and surgical blades asof their high prevalence in nosocomial infections. Nutrient agar plates were used to check the antimicrobial activity of coated surgical fabric whereas Muller Hinton agar plates were used to confirm antimicrobial activity of coated surgical blades. Whole procedure was carried out inside flow cabinets to avoid contamination.

2.5.2. Bacterial zones of inhibition assay

Each of the bacterial isolates was streaked individually on nutrient agar plates and was incubated for 24 h at 37 °C to allow microbial colonies to grow. The microbial colonies from 24 h cultured plates were selected via sterile loop and diluted in 0.9 % autoclaved normal saline solution with 300 μl of microbial inoculum from normal saline solution pipetted out and dropped into the nutrient agar plates and Muller Hinton agar plates. The sterilized spreader was then used to spread the inoculum evenly throughout the plates. Coated fabric swatches of square shapes and 5 × 3 cm in size were placed onto nutrient agar plates and gently pressed against the agar surface to ensure proper contact same procedure followed for placing coated surgical blades onto Muller Hinton agar plates. Uncoated blade sample was used as negative control. Both the nutrient agar plates as well as Muller Hinton agar plates were then incubated at 37 °C for 24 h. To increase precision and accuracy each experiment was performed three times and average values of zone of inhibition (ZOI) were calculated using standard formula; $W = (T - D)/2$. Where, 'W' represents ZOI (in mm), 'T' is total diameter (in mm) of clear zone and test sample & 'D' is diameter (in mm) of the zone of inhibition of the test sample.

2.6. Anti-biofilm activity of coated objects

2.6.1. Twenty-four hours treatment

Among six nosocomial infection causing bacterial species, *P. aeruginosa* was selected for testing anti-biofilm activity of coated objects as it is the most frequent microbial pathogen in patients with long-lasting infections. Biofilm of *P.aeruginosa* was formed by growing 50 μl of bacteria in 5 ml of autoclaved Luria Bertani broth (LB, dissolving 2g sodium chloride, 2g tryptone and 1g yeast extract in distilled water) for 48 h in shaking incubator at 37 °C. The 48 h bacterial culture of *P. aeruginosa* was grown in tryptone soya broth (TSB) at 37 °C overnight.

Silver nanoparticles coated surgical fabric and surgical blades were used for biofilm inhibition studies. With 50 μl of bacterial inoculum grown overnight in TSB brought out and released onto the coated fabric swatches and blades, placed in 6-well Microtitre plate. The uncoated fabric and blade samples were placed in Microtitre plate and studied for comparative analysis. With 6 ml of new TSB was placed over coated samples to allow nutrients for bacterial growth, the well plates were then incubated at 37 °C for 24 h in normal conditions. Inside the flow hood, fabric and blade samples were removed from microtitre plate very carefully using forceps after 24 h and were subsequently washed thoroughly with 1X PBS to get rid of planktonic cells. The samples were then subjected to SEM analysis.

2.6.2. SEM analysis of anti-biofilm activity of coated objects

Coated samples exposed to biofilm inhibition assay were organized and attached for SEM analysis. As a primary fixation, 4 % paraformaldehyde (PFA) was made and 100–200 μl of PFA was released onto coated samples inside laminar flow hood, left to air dry for 30–45 min. Samples were picked carefully using forceps and shriveled by submerging in different concentration of chilled ethanol (25 %, 50 %, 75 %, 95 % and 100 %) for 2–3 min. Samples were dried and packed airtight in sterile plastic plates and stored at 4 °C until used for SEM (JSM 6490LA) analysis. The scanning electron microscopy results of coated and uncoated samples were then analyzed for biofilm demolition in Image J-model software.

2.6.3. Confirmation of biofilm inhibition through CFU method

For quantification of total number of bacteria, suspension of coated and uncoated sample left behind in 6-well microtitre plate was analyzed with spectrophotometer and OD was recorded. The aliquots of suspension were diluted in 0.9 % saline through serial dilution, 100 μl of each dilution was spread on nutrient agar plate and incubated for 24 h at 37 °C. Bacterial colonies were counted through CFU method.

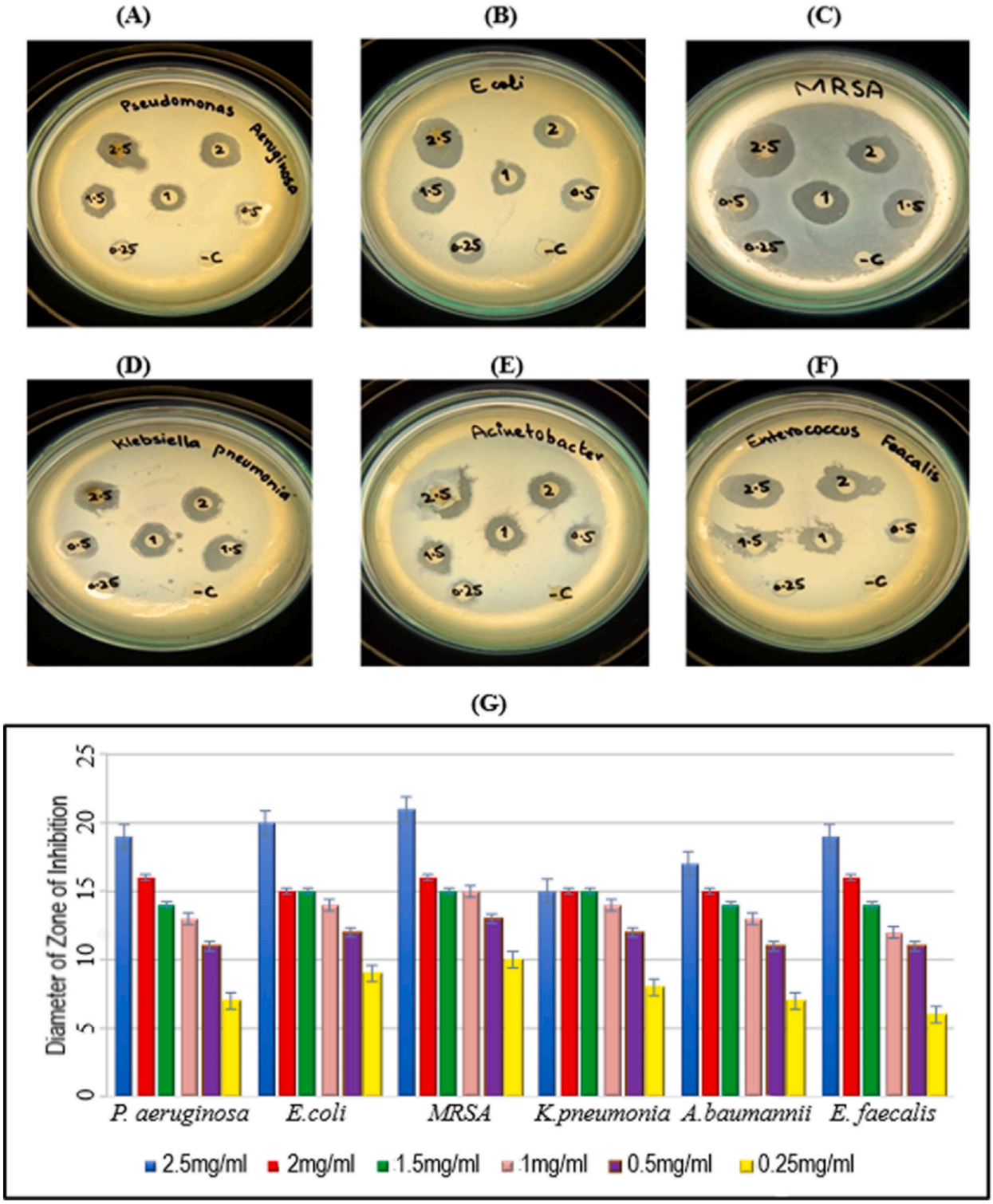

Fig. 1. Digital images of disk diffusion assay performed on different bacterial species at dfferent concentrations of AgNPs (A) Pseudomonas aeruginosa (B) Escherichia coli (C) MRSA (D) Klebsiella pneumonia (E) Acinetobacter baumannii (F) Enterococcus feacalis (G) Graph representing zone of inhibitions of AgNPs against bacterial species at different concentrations.

2.7. Silver release profile of coated object

The release of silver nanoparticles from coated objects was calculated using UV–vis Spectrophotometer (Model UVD-2950) in static conditions. The phosphate buffered saline (PBS) was prepared and pH was set at 7.4 [21]. The coated surgical fabric and coated surgical blade were coiled and placed in separate beakers containing 20 ml of PBS at 37 °C and stirred at 100 rpm. After every 1 h, old PBS was replaced with 20 ml of new PBS. This procedure was repeated for a period of 4–5 h. The PBS solution comprising released Ag was examined using UV–Vis at 430 nm at different time period to determine silver release time profile. The experiment was performed in triplicates and average result was calculated.

2.8. Washing durability of coated surgical fabric

For industrial concern washing durability of coated surgical fabric was carried out as per the AATCC 61 (2A) test method [22]. In this process, silver nanoparticle treated fabric swatches were washed using 1 g/L of SDS (Sodium dodecyl sulfate) detergent. Four cycles of washing were performed and each cycle was for 45 min at 50 °C in ultrasonic bath. After 45 min, the fabrics were rinsed with distilled water followed by air drying. One washing cycle of the method which was followed is equivalent to five cycles of hospital setting laundering in ambient conditions at 38±3 °C. 1, 2, 3 and 4 washing cycle is equal to 5, 10, 15 and 20 hospital setting laundering cycles, respectively. The durability of AgNPs on the fabric surface was assessed by performing scanning electron microscopy (SEM) analysis.

3. Results

3.1. Antibacterial activity of silver nanoparticles

The results of antibacterial effect of AgNPs against six bacterial species i.e., *P. aeruginosa, E. coli*, MRSA, *K. pneumoniae, A. baumannii and E. faecalis* showed that as the concentration of AgNPs increased, the diameter of zone of inhibition (ZOI) increased accordingly. It was observed that biologically synthesized silver nanoparticles were active against all the tested bacterial species. The maximum inhibitory diameter observed at 2.5 mg/ml silver nanoparticle concentration was 21 mm against MRSA and minimum diameter of ZOI recorded was 15 mm against *K. pneumoniae*. Furthermore, diameter of ZOI recorded at AgNPs concentration of 2.5 mg/ml was of 20 mm in *E. coli*, 19 mm in *P. aeruginosa* and *E. faecalis* and 17 mm in *E. baumannii*. Deionized water used as a negative control exhibited no zone of inhibition. For positive control no antibiotic was used as our main focus to confirm the antibacterial activity of AgNP's synthesized from *Aerva javanica* plant, as nanoparticles were also acquiring functional groups from plant extracts which enhances antibacterial activity of AgNP's also the toxic effect of these nanomaterials decreases because of other compounds acquired from plant extracts. Results of antibacterial activities of AgNPs against six bacterial species are shown in Fig. 1(A–G).

3.2. Characterization of coated objects

3.2.1. Optical microscopy (OM)

Optical microscopy confirmed the existence of AgNPs on coated fabric. Both coated and uncoated fabric swatches were visualized under microscope at magnification of 5x, 10x, 20x and 50x. Result showed the difference in the appearance of coated and uncoated

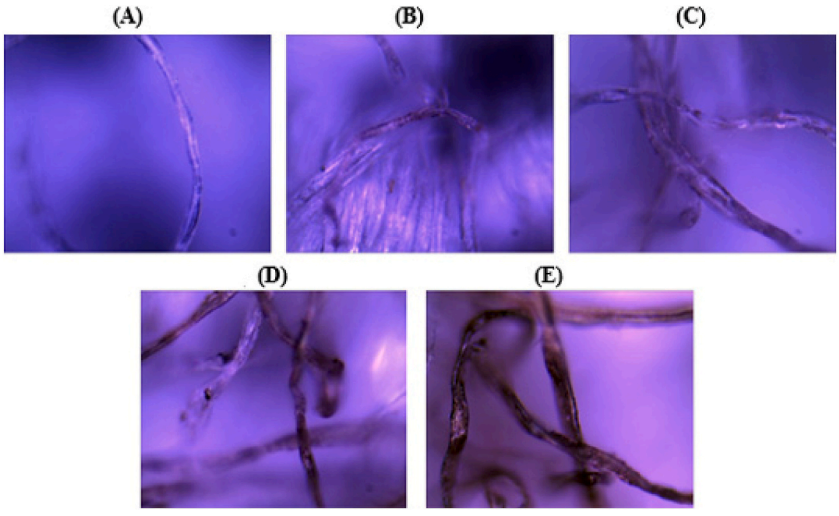

Fig. 2. Optical Microscope images of uncoated & coated fabric samples (A) Uncoated sample (B) 5 layers (C) 10 layers (D) 15 layers (E) 20 layers.

samples and i reveals the difference between the samples having different number of layers. It was observed that silver nanoparticles imparted brownish color to the coated fabric and the intensity increased with increasing number of layers with 20 layers coated fabric appearing darkest in color. The uncoated sample remained colorless showing the absence of silver nanoparticles (Fig. 2A–E).

3.2.2. Optical profilometry (OP) analysis

Optical profilometry is a rapid and nondestructive metrology technique used to confirm the surface structure and to calculate average roughness of surface without affecting other features. It also helps to characterize coating thickness. The results of OP of coated and uncoated fabric showed that roughness of fabric's surface decreased with the increase in the number of coated layers. The 20 layers coated fabric showed an average roughness of 25295 nm compared to the average roughness of 73223 nm in the case of uncoated fabric. Similarly, mean roughness of 56357 nm, 39047 nm, 35654 nm, 34259 nm was observed in 1, 5, 10 and 15 layers coated fabric, respectively. Table 1 shows results of optical profilometry analysis of AgNPs coated fabric samples.

3.2.3. Scanning electron microscopy and energy dispersive X-ray (EDX)

The SEM result of coated fabric demonstrated that spherical AgNPs were dispersed on the sample's surface. It was observed that coating density of silver nanoparticles changed with increasing number of layers i.e., 20 layers coated fabric showed maximum coating in form of AgNPs aggregates. The 2,500×-magnification images clearly revealed silver nanoparticles coating on the surface of fabric. SEM results of coated blade reveals successful deposition of silver nanoparticles on surgical blades. Some grooves were also visible on the surface of coated blade. Micrograph confirms the presence of aggregated AgNPs on coated surgical blades. The formation of aggregates can be attributed to the high concentration of nanoparticles being coated on blade. The results of SEM analysis of coated fabric samples and coated surgical blades are shown in Fig. 3(A–E).

Energy Dispersive X-ray (EDX) technique was used for further confirmation of deposition of silver nanoparticles within coated material. The results of EDX analysis of coated fabric and coated blades are shown in Fig. 4. A peak at 3 keV observed in EDX spectra of both coated fabric and coated blade confirmed the presence of AgNPs. EDX spectra of surgical blades revealed the presence of silver and iron along with carbon and oxygen. The quantity of incorporated AgNPs on the sample surface varied by changing nanoparticle concentration. Elemental details of silver coated fabric samples and blades are shown in Table 2.

3.2.4. Fourier transform infrared spectroscopy (FTIR)

The FTIR analysis showed the surface chemistry and functional groups present on AgNPs coated fabric and coated blade. Some major peaks recorded in the spectrum of AgNPs were at 3417 cm^{-1}, 2924 cm^{-1}, 1651 cm^{-1}, 1406 cm^{-1},1029 cm^{-1}, 686 cm^{-1} which corresponds to the presence of O–H, C–H, C=C, -C-H, C–O and = C–H, respectively. On the other hand, peaks at 3313 cm^{-1}, 2903 cm^{-1}, 1648 cm^{-1}, 1024 cm^{-1} noted in the spectrum of coated fabric can be correlated to the presence of O–H, C–H, C=C and C–O groups, respectively. FI-IR spectra of coated blades showed peaks at 2169 cm^{-1}, 1638 cm^{-1},1055 cm^{-1} and 786 cm^{-1} which indicate the presence of functional groups C≡ C, C=O, C–O, =C–H, respectively. Presence of several common peaks in spectra of coated fabric, coated blades and AgNPs provide the evidence of successful coating of AgNPs on fabric and blades. The results of FTIR spectroscopy analysis presented in Fig. 5 clearly indicates common functional groups present on the surface of AgNP's and also on nano-fabrics and surgical blades include C–O, C–H, C=C etc These groups might be involved in coating of AgNPs with the surface of fabric. Also in case for nano-fabric PDAC is positively charged which binds with AgNP's with electrostatic interactions, this electrostatic interaction may also be the reason of binding of AgNPs onto the surface of fabric.

3.2.5. X-ray diffraction (XRD)

The crystalline nature of AgNPs entrapped on the surface of fabric and blades was determined by XRD analysis. X-ray diffractogram of silver treated fabric showed diffraction peaks at angles 44.28°, 64.4° corresponds to Ag (200) and (220), respectively [23]., In the case of surgical blades the diffraction peaks were detected at 2θ value of 44° corresponding to the (200) plane and at 2θ value of 64° corresponding to the (220) plane [24]. These peaks were the confirmation of crystalline nature of silver nanoparticles on the surface of fabric and blades. Fig. 6 A and B confirms the results of XRD analysis of coated objects.

3.3. Antibacterial activity of coated objects

3.3.1. Zone of inhibition assay

Antibacterial results of coated fabric show that silver-treated fabric demonstrated good antibacterial effects by inactivating bacterial growth. Increasing the concentration of AgNPs coating caused an increase in diameter of ZOI as shown in Fig. 7(A–G). Maximum diameter of approximately 6 mm observed around the 20 layers coated fabric swatch against *E. faecalis* while minimum diameter of ZOI of 2 mm recorded against *K. pneumoniae.* It was noted that silver nanoparticles coated fabric swatches were active against all tested bacterial species. In the case of surgical blades (Fig. 7A–G) maximum diameter of ZOI noted was 4 mm against *A. baumannii* and MRSA while, minimum zone of inhibition diameter recorded was 2 mm against *K. pneumoniae*. As observed in the control, uncoated blade

Table 1
Average roughness (nm) of uncoated and coated fabric samples calculated by optical profilometry.

Average Roughness (nm)	Uncoated	1 Layer	5 Layers	10 Layers	15 Layers	20 Layers
	73223	56357	39047	35654	34259	25295

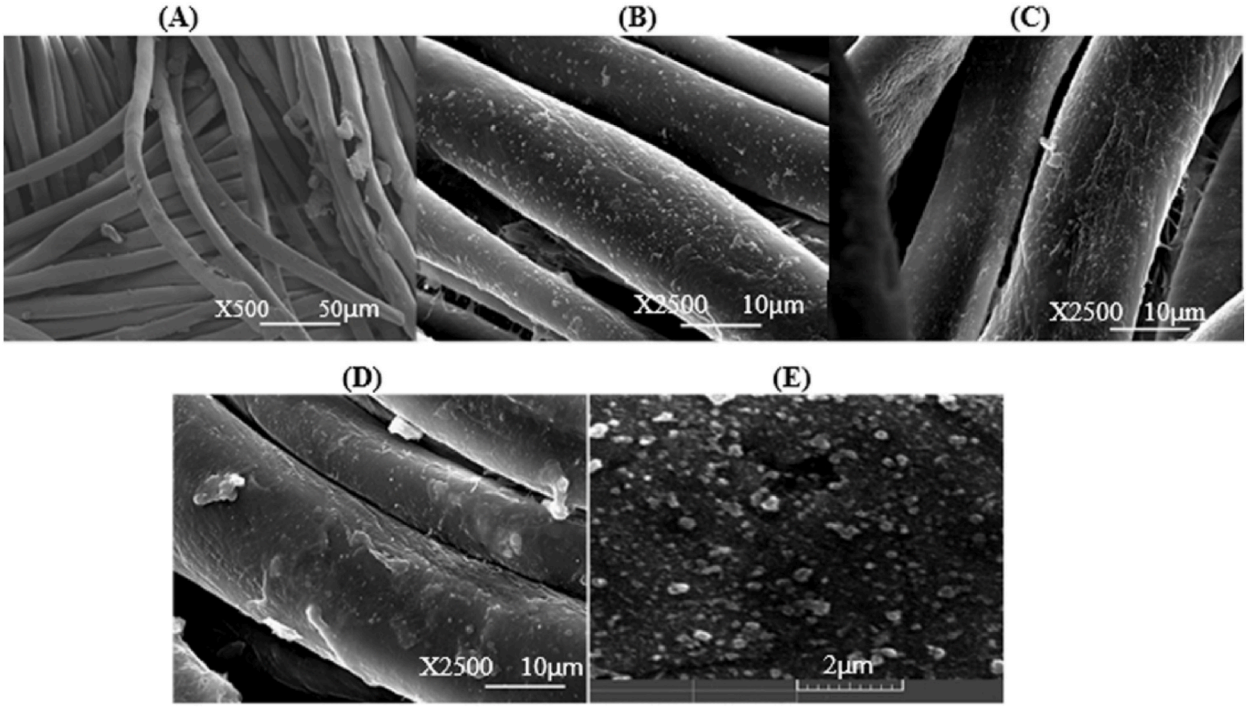

Fig. 3. SEM images of silver nanoparticles coated fabric samples (A) Uncoated (B) 10 layers (C) 15 layers (D) 20 layers (E) SEM image of silver nanoparticles coated surgical blades.

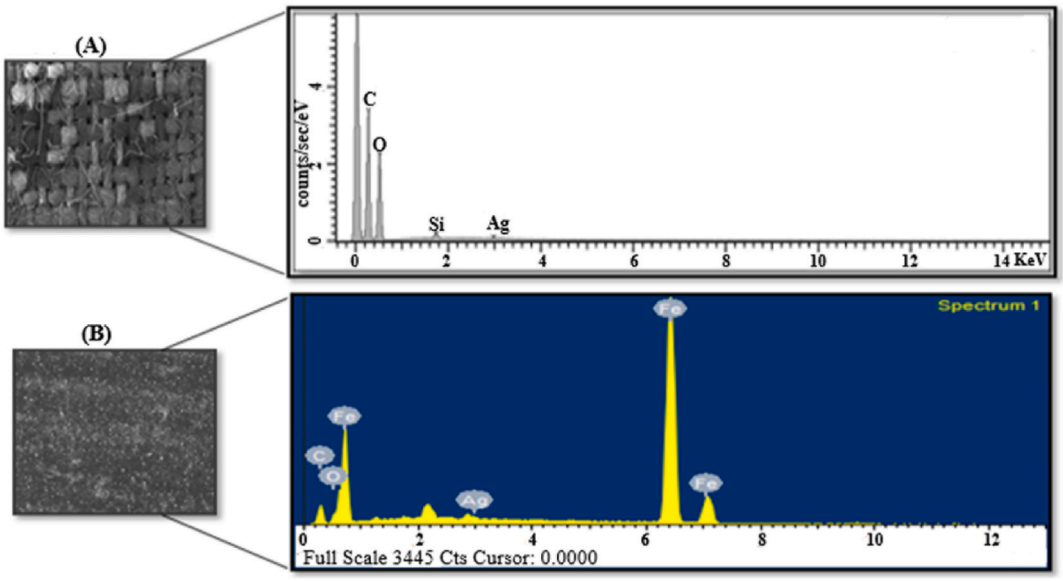

Fig. 4. Energy Dispersive X-ray (EDX) analysis of coated objects (A) coated fabric (B) coated blades.

showed no inhibition of bacterial growth. This supports the idea that antibacterial activity of surgical blades was because of AgNPs coated on them Fig. 8(A–G). For positive control no antibiotic used as our main focus was to confirm the antibacterial activity of AgNP's synthesized from *Aerva javanica* plant, as nanoparticles were also acquiring functional groups from plant extracts which enhances antibacterial activity of AgNP's also the toxic effect of these nanomaterials decreases for the reason that of the other compounds acquired from plant extracts. While confirming antimicrobial activity of AgNP, deionized water was used as a negative control, exhibited no zone of inhibition. Whereas confirming antimicrobial activity of AgNP coated blades, the uncoated blade was used as a control, showed no inhibition of bacterial growth. As evident from the washing experiments even after 20 cycles of standard

Table 2
Elemental details of silver coated fabric.

Objects	Elements	Weight %	Weight % Sigma
Coated Fabric	**C**	50.19	0.44
	O	49.14	0.45
	Si	0.37	0.02
	Ag	0.31	0.06
Coated Blades	**C**	26.07	1.24
	O	5.09	0.62
	Fe	68.79	1.24
	Ag	0.05	0.21

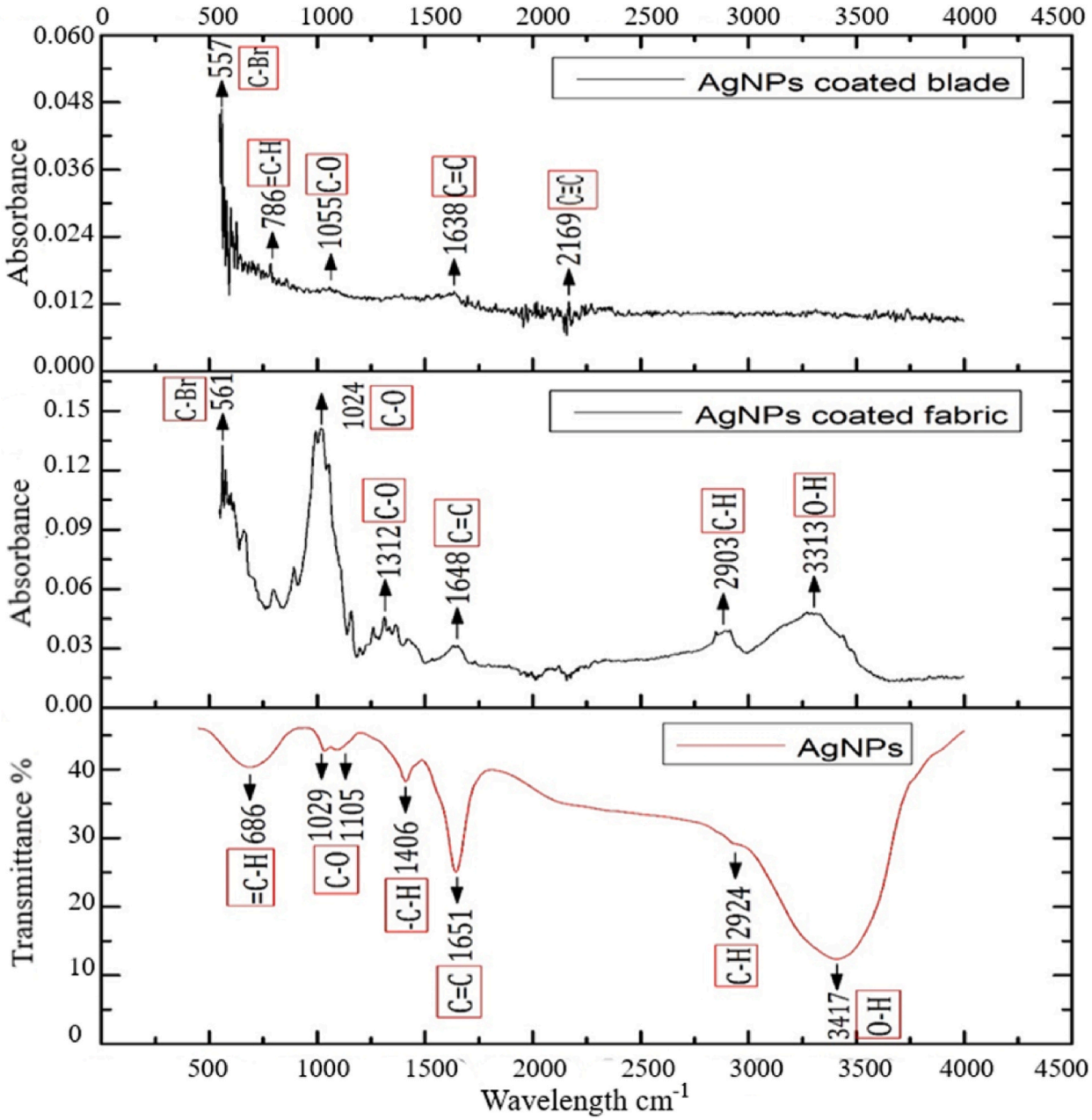

Fig. 5. FTIR spectra of coated fabric & coated blade with reference to AgNPs.

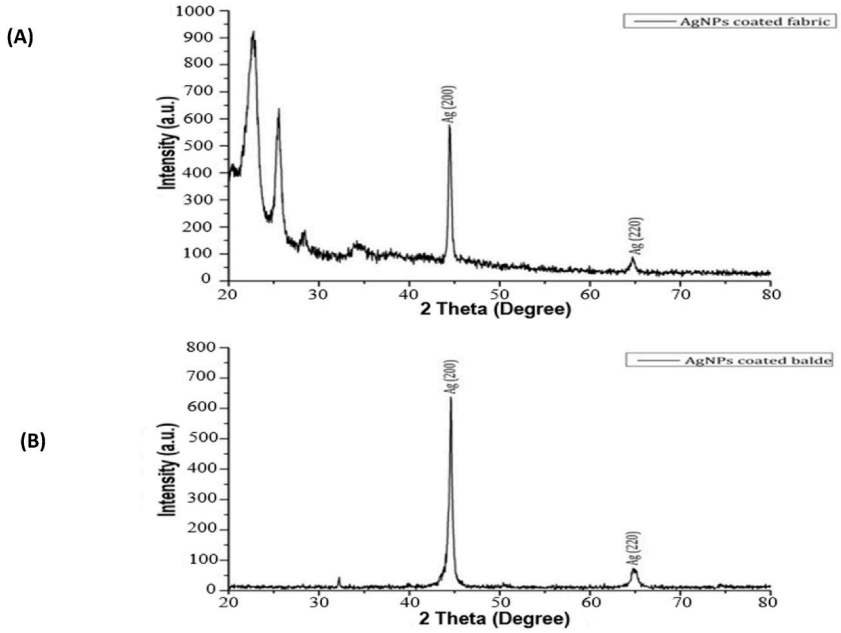

Fig. 6. XRD spectra of coated objects: (A) coated fabric (B) coated blade.

laundering in hospital settings, AgNP's coatings were stable on nano-fabrics and nano-surgical plates, therefore there are very less chances of leaching of AgNP's during antibacterial assays on the agar plates and immediate contact of AgNP's on the nano-fabric and nano-surgical blades would destroy the bacterial cells as evident from SEM images while performing anti-biofilm assays of nano-fabric and nano-surgical blades.

3.4. Anti-biofilm activity of coated objects

3.4.1. SEM analysis of anti-biofilm activity of coated objects

Silver nanoparticles coated objects were tested for anti-biofilm activity against selected bacterial species i.e., *P. aeruginosa*. SEM images of uncoated fabric show bacterial biofilm formation after 24 h treatment. The morphology of bacteria remained intact in uncoated fabric and biofilm formation was observed. Conversely, AgNPs coated fabric showed no signs of bacterial biofilm formation. Similarly, uncoated blade illustrated rod shaped bacterial cells and it was observed that biofilm production remained unimpeded in this case whereas; a clear disruption of biofilm was observed in AgNPs coated blade (Fig. 9A–F).

3.4.1.1. J-model analysis of biofilm formation. Image J software (https://imagej.nih.gov/ij/) was used to observe 3D images of coated and uncoated objects after 20-h treatment of biofilm. Coated objects showed irregular depressions on the surface with apparent distortion in morphology which can be attributed to the presence of disrupted biofilms whereas morphology of bacterial cells of uncoated objects depicted the presence of uniform shaped bacteria. Fig. 10(A–D) demonstrate J-Model Analysis of 3-D images.

3.4.2. Confirmation of biofilm inhibition through CFU method

The *P. aeruginosa* suspension of coated and uncoated sample left behind in 6-well microtitre plate was analyzed for biofilm inhibition through colony-forming units' method. It was observed that AgNPs coated biofilm suspension showed a remarkable bactericidal effect against *P. aeruginosa* with very fast killing-kinetics as compared to uncoated biofilm suspension. Table 3 demonstrates the calculated CFU of coated and uncoated sample. At dilution factor 10^{-4}, the number of viable bacterial cells was found to be 122 CFU in coated suspension while 18 CFU in uncoated suspension. Similarly, at dilution factor 10^{-5}, the number of viable bacterial cells were found to be 85 CFU in coated suspension while 5 CFU in uncoated suspension.

As apparent in Fig. 11(B) the coated suspension sample showed less or no viable colonies on agar plate which clearly indicates the killing of bacterial cells. However, the uncoated suspension demonstrated uncountable growth of colonies as shown in Fig. 11(A). The colony count was found to be significantly reduced with the increasing concentrations of nanoparticles. Table 3 shows counted CFU of coated and uncoated bacterial suspension sample.

3.5. Silver release profile of coated objects

The silver release profile of AgNPs coated fabric and blade was measured using UV–visible Spectrophotometer based on 430 nm wavelength. Concentration of AgNPs released from the surface of fabric and blade in aqueous PBS was recorded in mg/ml at different

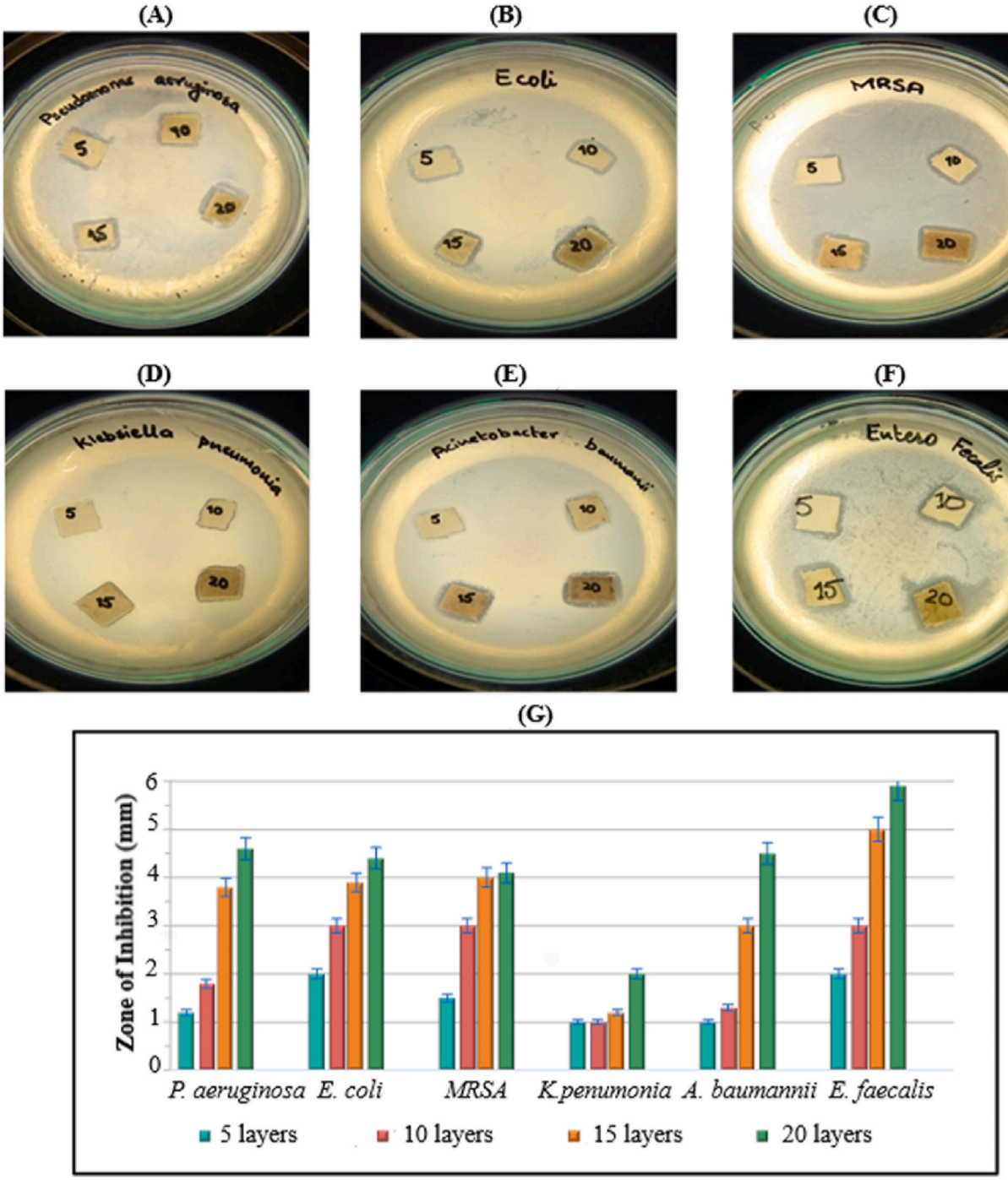

Fig. 7. Digital images of zone of inhibition of coated fabric (A) *Pseudomonas aeruginosa* (B) *Escherichia coli* (C) MRSA(B) *Klebsiella pneumonia* (E) *Acinetobacter baumannii* (F) *Enterococcus faecalis* (G) Graph representing zone of inhibition of coated fabric against bacterial specie.

time intervals. Results demonstrated that release rate was highest after 1 h of the treatment with PBS which may due to the detachment of loosely attached silver from the substrate whereas in later hours the release rate remained almost constant. It was observed that 0.035 mg/ml and 0.054 mg/ml concentration of AgNPs released from coated fabric and coated blade, respectively after 1 h of dipping in PBS. The release rate was primarily less (approx.10 %) in the later hours which can be attributed to the presence of strong association of remaining AgNPs with fabric swatches and blades. The results of silver release profile of coated objects are presented in Fig. 11(C).

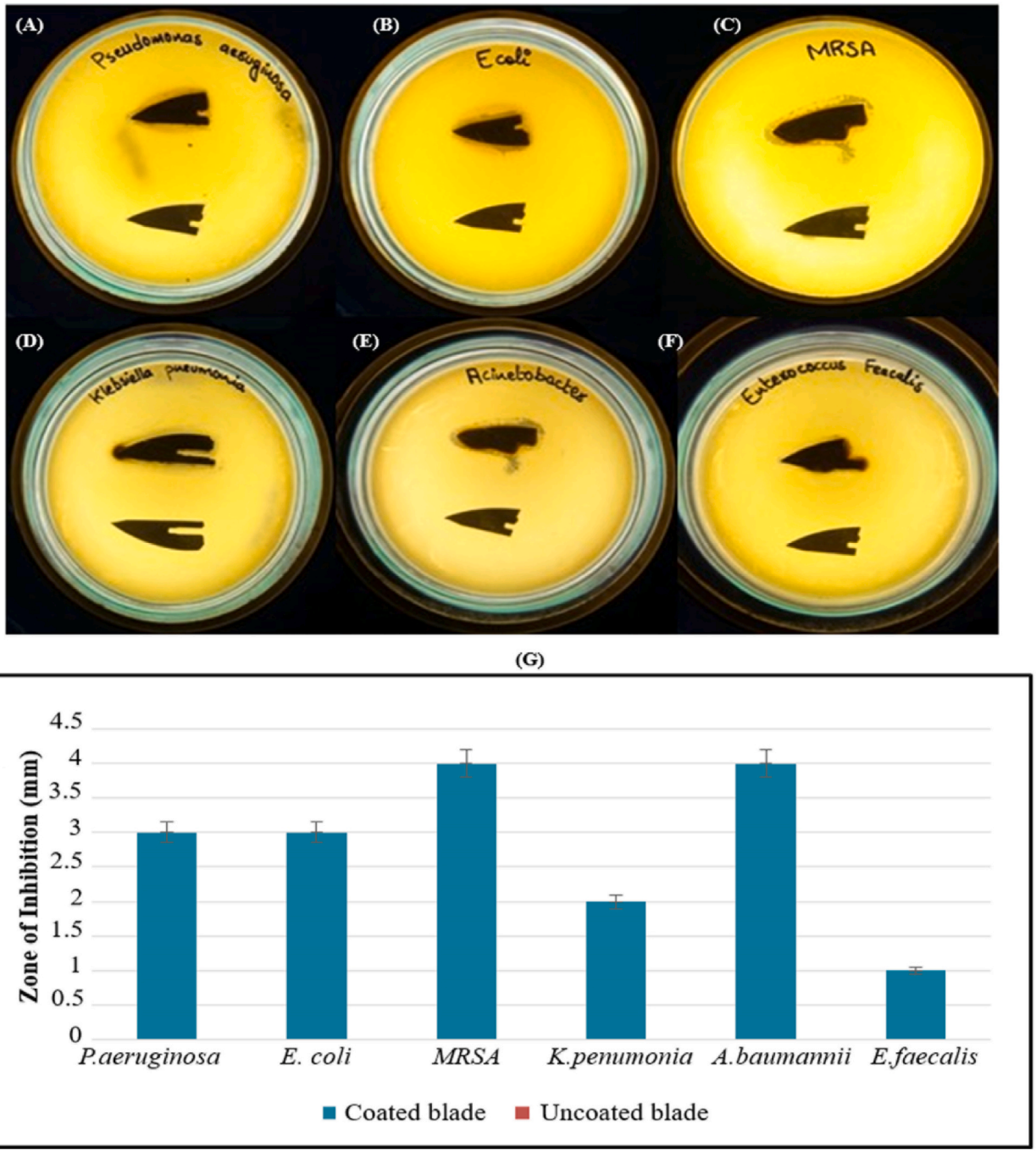

Fig. 8. Digital images of zone of inhibition of coated blade (A) *Pseudomonas aeruginosa* (B) *Escherichia coli* (C) MRSA (D) *Klebsiella pneumonia* (E) *Acinetobacter baumannii* (F) *Enterococcus feacali.* (G) Graph representing zone of inhibition of coated blade against bacterial specie.

3.6. Washing durability of coated surgical fabric

Scanning Electron Microscopy (SEM) analysis was performed to confirm the durability of AgNPs on surface of the fabric. The AgNPs coated fabric had excellent washing properties, as these nanoparticles were still conjugated on the surface of coated fabric even after 5 extensive washing steps. Fig. 11 illustrates the SEM image of the washed fabric which showed the presence of AgNPs in the form of small spherical beads. The results prove that silver nanoparticles were strongly attached on the surface of fabric and coating was extremely durable even after substantial number of standard launderings. This treatmentremains stable and it can be assumed that fabric retains its antimicrobial activity even after extensive washing. Fig. 11(D) and (E) show the SEM images of unwashed and washed

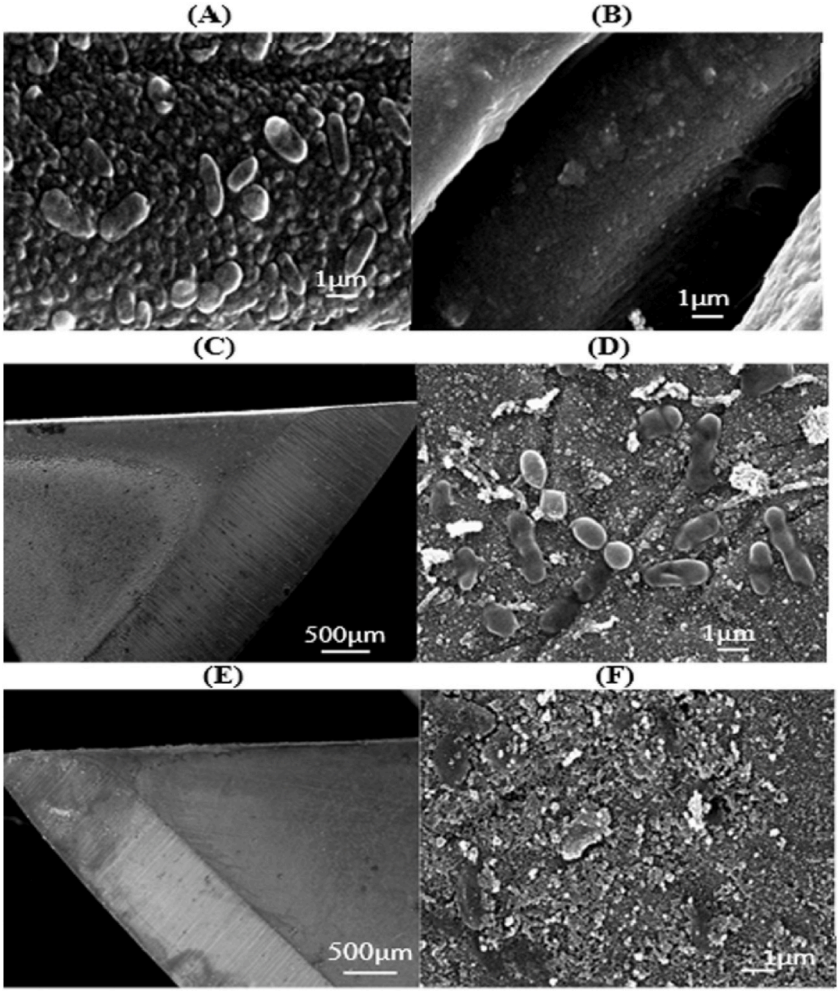

Fig. 9. SEM images of biofilm formation of *Pseudomonas aeruginosa* (A) uncoated fabric (B) AgNPs coated fabric (C and D) uncoated blades (E and F) AgNPs coated blades.

fabric after 5 extensive washing steps.

4. Discussion

Since the last few years, metallic nanoparticles (NPs) have been a source of fascination for researchers owing to their exclusive physicochemical properties [25]. AgNPs are predominantly exceptional candidate for research because of their diverse potential applications in biomedical fields [26]. Recently, comprehensive interrelated experimentations have been carried out to investigate antibacterial activities of AgNPs. In the current study, antibacterial activities of biologically synthesized AgNPs were tested against different pathogenic microorganisms including both gram positive and gram negative bacteria which showed different zones of inhibition. AgNP usually shows higher inhibition against Gram-negative bacteria compared to Gram-positive bacteria as Gram-negative bacteria have a thick LPS layer in their cell wall with a thin peptidoglycan layer in contrast to Gram-positive bacterial cell walls contain thin LPS and thick peptidoglycan layers. However that was not the case always as there were many studies which prove greater inhibition of AgNP against Gram-positive bacteria compared to Gram-negative bacteria. In the current study, results demonstrated varying zones of inhibition, indicating differential antibacterial efficacy. The reported mechanisms through which silver nanoparticles exert their antibacterial effects include attachment to thiol groups on bacterial enzymes [27], intercalation with negatively charged DNA [28], and interference with cell wall synthesis [29]. The antibacterial activity of silver nanoparticles is influenced by several factors such as their size, shape, charge, and the capping agent used in their synthesis. Additionally, the genetic makeup of bacterial strains play significant role in determining their resistance to nanoparticles. However it is also been reported bacterial resistance to AgNPs may be acquired through mutations in bacterial genomes as due to the lack of Oxygen ROS production by AgNPs would be minimal, low level of ROS may stimulate the presence of resistance due to oxidative stress and increased mutation rates in bacteria [49].

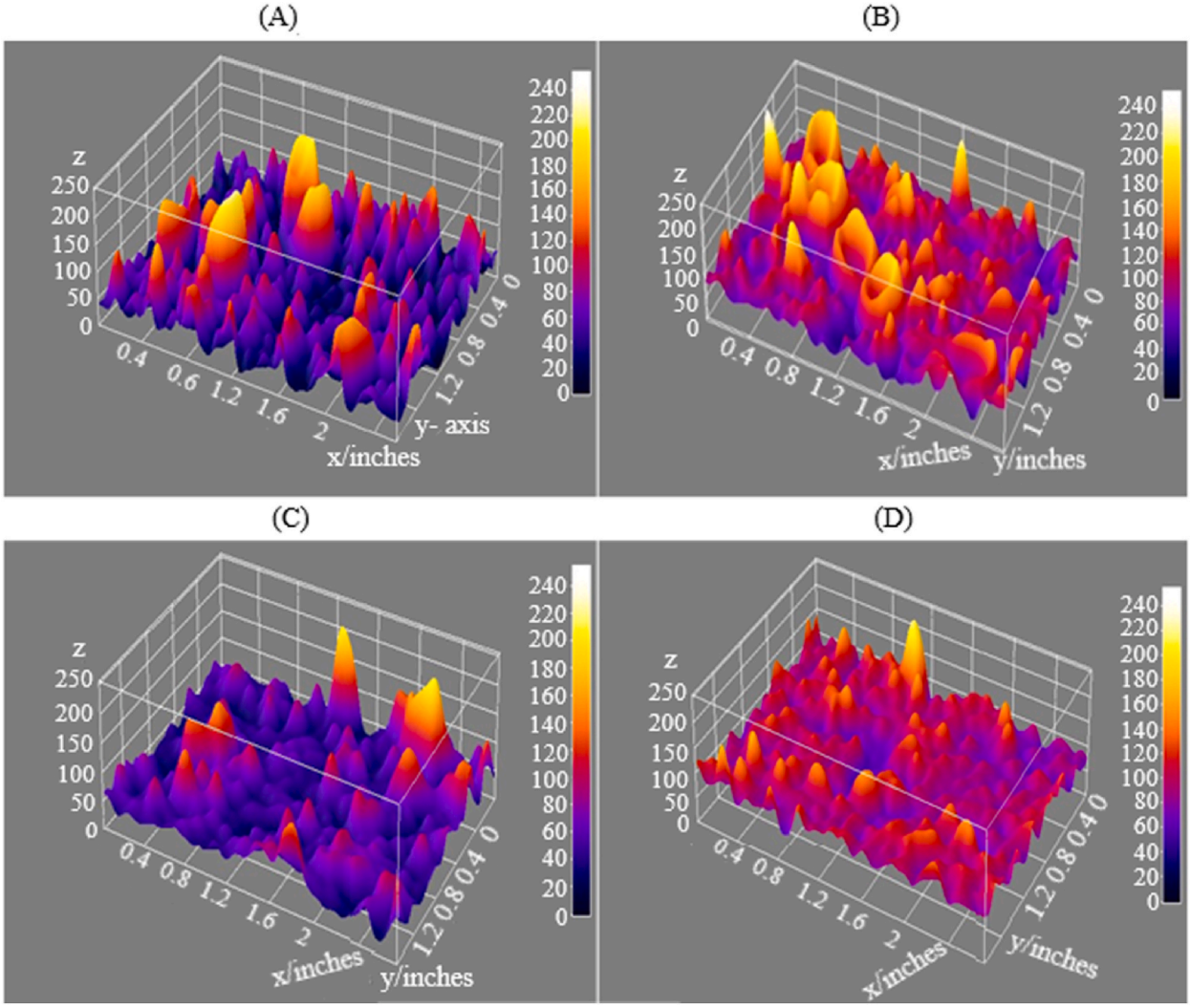

Fig. 10. J-Model Analysis of 3-D images (A) uncoated fabric (B) coated fabric (C) uncoated blade (D) coated blade.

Table 3
Counted CFU of coated and uncoated bacterial suspension sample.

Dilution Factor	Bacterial suspension of a coated sample		Bacterial suspension of uncoated sample	
	No. of colonies	CFU	No. of colonies	CFU
10^{-1}	Uncountable	–	54	5.4×10^{-3}
10^{-2}	Uncountable	–	31	3.1×10^{-4}
10^{-3}	Uncountable	–	20	2.0×10^{-5}
10^{-4}	122	1.22×10^{-7}	18	1.8×10^{-6}
10^{-5}	85	8.5×10^{-7}	5	5×10^{-6}
10^{-6}	42	4.2×10^{-8}	0	–

The green synthesized AgNP is considered as a promising solution for the future as they are much smaller and more easily absorbed compared toAg. Whereas AgNPs are widely used in every field such as in medical devices, wound dressings, bandages, and face masks due to their potent antimicrobial properties [47]. This helps prevent infections and promotes healing, making them indispensable in medical settings. AgNPs are valued for their excellent electrical conductivity, thermal stability, and robustness [48]. These properties make AgNPs ideal for their use in various electronic components and devices. Textiles treated with AgNPs can provide protection against harmful ultraviolet rays. The use of AgNPs in military clothing and sportswear offers durability, antimicrobial properties, and comfort. Also AgNPs are employed to enhance the safety and shelf life of food products. Their antimicrobial properties help in reducing spoilage and extending the freshness of food items during processing and storage.

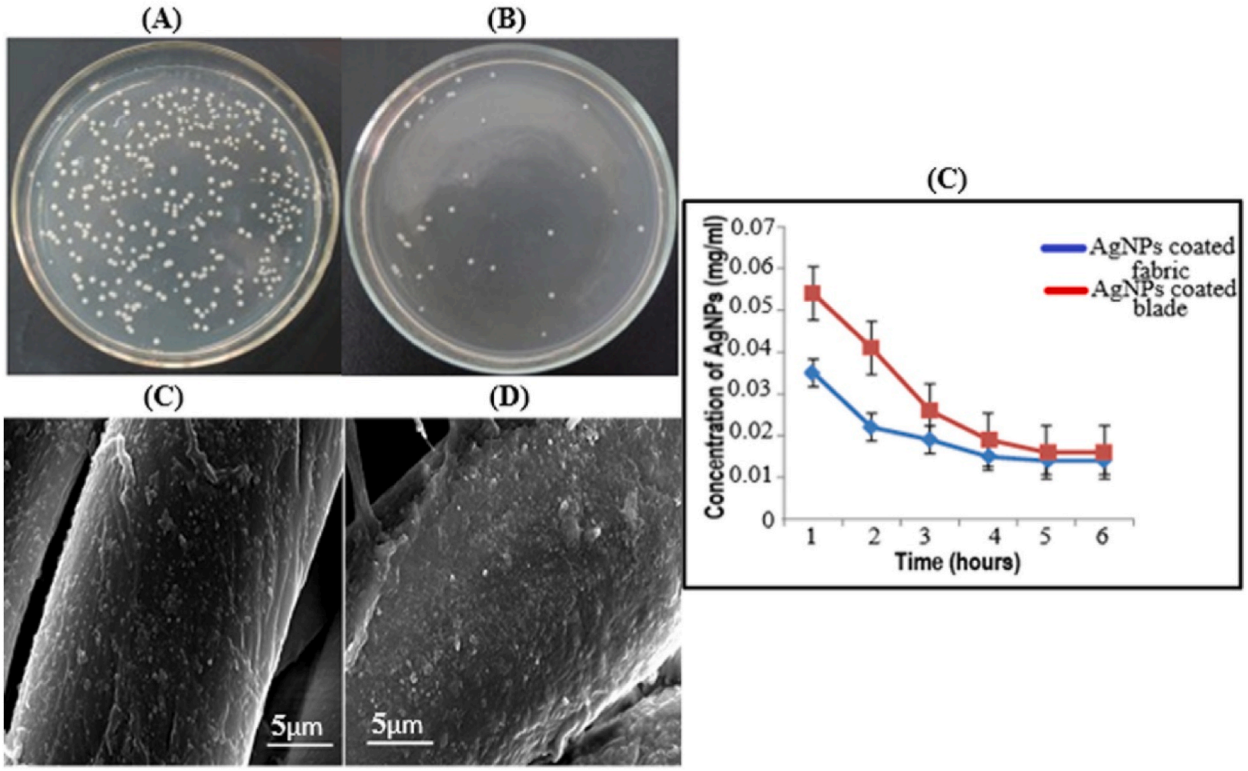

Fig. 11. *Pseudomonas aeruginosa* colonies formation on nutrient agar plates (A) Uncoated sample suspension (B) Coated sample suspension. (C) Silver release profile of uncoated and coated fabric at different time interval (D) Scanning electron microscope images of unwashed fabric (E) Scanning electron microscope images of washed fabric.

The antibacterial activity differs among different nanoparticles and course of functioning of silver nanoparticles mainly depends on size, shape, charge and capping agent of synthesized nanoparticles [30–33]. Also, bacterial genomes play a key role in microbial resistance to nanoparticles [34]. Previous study has shown that chemically synthesized AgNPs with radii 10 and 20 nm showed antibacterial activity against MRSA, *E. coli, P. aeruginosa* even at lower concentrations [35]. In a study 0.002 mg of nanoparticles when tested for their antibacterial activities against MRSA recorded a zone of inhibition of diameter 17.5 mm [36]. Similarly another study reported that AgNPs of size 51.10 nm at the concentration of 15 µg/ml produced a zone of inhibition of diameter 13.86 ± 0.30 mm in *K. pneumoniae* [37]. Also, a nanocomposite of AgNPs stabilized with xanthan gum at a concentration of 500 mg/ml produced a zone of inhibition of 10.6 ± 0.6 mm, 11.6 ± 0.5 mm, 10.8 ± 0.5 mm and 10.0 ± 1.0 mm in *A. baumannii*, *E.coli, E. faecalis and P. aeruginosa*, respectively [38]. Another study have shown antibacterial activities of AgNPs against water borne pathogens [39]. The results of antibacterial activity of AgNPs against gram positive and gram negative bacteria with highest inhibitory diameter of 21 mm and lowest inhibitory diameter of 15 mm observed against MRSA and *K. pneumoniae*, respectively provide evidence that AgNPs synthesized in the current study are effective antibacterial agents.

HAIs which are common in both developing and developed countries are major concern for the safety of patients. To prevent HAIs many medical and implantable devices such as insulin pumps and catheters are coated with AgNPs to prevent microbial infections [40]. Present work reports the use of biologically synthesized silver nanoparticles to develop surgical fabric and surgical blade showing antibacterial activities. This study proves that it was possible to coat fabric with silver nanoparticles using simple and facile layer-by-layer technique. Complete adherence of silver nanoparticles on fabric surface was because of polymer PDAC used as a cationic solution and silver nanoparticles were used as anionic solution. Because of the presence of oppositely charged particles, electrostatic force of attraction developed and AgNPs got deposited on the fabric surface already dipped in cationic PDAC. Due to the presence of electrostatic interactions between positively charged PDAC Polycations and negatively charged Ag particles, deposition at the top surface will be significant. It is expected after compensation of positive and negative charges, excess charges surface would arise from Ag ions. Previously, ZnO nano-composite film had been deposited on the surface of fabric. Pre-treated fabric was dipped sequentially in anionic (zinc oxide) and cationic (2,3-epoxypropyltrimethylammonium chloride) solution with a washing step in between. ZnO nanoparticles were successfully deposited onto cotton fabric. This type of coating however did not provide desired properties to product [16]. Nanoparticles were also deposited onto the surgical blades by electrochemical deposition technique. Basic principle of this technique involves the movement of silver ions in the electrolyte to anode (surgical blades) thus, getting reduced and deposited onto the surface.

Optical microcopy analysis confirmed the deposition of AgNPs on the surface of fabric by showing the color change of fabric from

white to brown upon deposition with AgNPs. Optical microscopy results of a previous study also proved that color of uncoated fabric changed from white to brown when coated with AgNPs synthesize using *Peltophorum pterocarpum* flower extract [14]. Results from optical profilometry demonstrated that roughness of the fabric reduced as the number of coated layers was increased. Normally average roughness of a surface increases by increasing number of coating layers but an opposite trend was observed in this case. One possible explanation for this variation is that the rough surface of fabric surface was made smoother by AgNPs which filled the pores and spaces in the fabric to some extent. SEM analysis confirmed the deposition of spherical AgNPs on the surface of coated fabric and surgical blades. It was observed that as the number of coating cycles on fabric was increased the density of AgNPs on the surface was also increased. EDX spectra of coated fabric and blades confirm the signal characteristics of Ag^{+} ions. The peak observed at 3 KeV refers to the presence Ag nanocrystallites which exhibit optical absorption peak at this range due to their surface plasmon resonance [41].

FT-IR analysis is an essential tool for the identification of functional groups present on the surface of nanoparticles serve as capping and stabilizing agents. Some characteristic as well as common peaks were observed in the spectra of AgNPs, coated fabric and blades. Common peaks such as those attributed to the presence of O–H, C–H, C=C, C–O functional groups observed in the spectra of AgNPs and coated fabric provide evidence that AgNPs have successfully been deposited on the fabric surface. Also, the presence of common peaks correlating to existence of functional groups such as, C=C, C–O and = C–H observed in the spectra of AgNPs and coated blades confirms the deposition of AgNPs on surgical blades. Crystalline structure of AgNPs on coated surfaces was confirmed by XRD analysis. Peaks at the angles 44.28° and 64.4° observed in diffractogram of coated fabric and those observed at 44.28°, 64.4° in XRD spectrum of coated surgical blades provide evidence for the presence of crystalline structure of AgNPs. The results of XRD analysis of previous studies supported XRD results recorded in the current study [24,42,43].

AgNPs finished cotton fabric has wide potential application in hospital settings such as in coats and aprons for medical practitioners as they are continuously exposed to disease causing microorganisms. Apart from that antiseptic wound dressings can be made from AgNPs coated fabric. Previously, Lee et al. reported the antimicrobial effected of the AgNPs finished fabric against various types of bacteria including, gram positive, gram-negative and antibiotic resistant ones. Another study reported the skin-irritation tests of AgNPs coated fabric on guinea pigs demonstrated no side effects [44]. In this study, AgNPs coated surfaces were tested for their antibacterial activities through zone of inhibition assay and anti-biofilm activity test. Both the coated fabric (20 layers) and coated surgical blades were found to be the most effective against *E. faecalis* with ZOI of 6 mm and 4 mm, respectively. Whereas, these were least effective against MRSA and *K. pneumoniae* with ZOI of 2 mm recorded in both type of coated surfaces. Previous reports of antibacterial activities of AgNPs coated fabrics *against S. aureus, E. coli* and *P. aeruginosa* demonstrated that coated fabric was the most effective against *S. aureus* with the ZOI in diameter of 3 mm observed at silver content of 114.17 mg/kg [45]. Results of ZOI inhibition assay reported in the current study are comparable with the findings of previous studies. Anti-biofilm activity tests revealed that coated objects were very effective against inhibiting the biofilm formation. Nonetheless, there is a need for further studies to validate if the exposure of bacteria to nanoparticles results in the development of resistance against NPs also there is a need to test potential cytotoxic effects of nanoparticles on human cells before proceeding towards their clinical application.

The release of silver from the coated fabric and blades when treated with PBS buffer media revealed that loosely attached silver nanoparticles on coated surface removed within an hour. However, the release rate remains same for lateral hours due to strong association of residual AgNPs on the surface of coated objects. In addition to that washing durability of coated fabric reveled that silver nanoparticles remain in contact on fabric surface even after 5 cycles of washing which is equal to 20 hospital setting laundering. van der Waals forces and hydrogen bonding are responsible for remarkable laundering durability of AgNPs coated fabric. These forces enhance the bonding between silver nanoparticles and fabric [22]. Results from washing durability provide evidence that the AgNPs coated fabric will retain its antibacterial properties even after 20 hospital setting laundering procedures.

5. Conclusion

Biologically synthesized silver nanoparticles having antibacterial properties were coated on surgical fabric and surgical blade in a very simple and cost-effective manner. Characterization of coated objects was performed using optical microscopy, optical profilometry, SEM analysis, FT-IR and X-Ray diffraction analysis which provided evidence that AgNPs were successfully deposited on the surfaces of fabric and blades. The results of OM showed that the coating of AgNPs imparts brownish color to fabric whereas; the OP results demonstrated that roughness of fabric was reduced as the number of layers of AgNPs coated on fabric was increased. The results of SEM analysis revealed the presence of AgNPs on the surface of coated fabric and blade. Similarly, FTIR spectra of AgNPs, AgNPs coated fabric and AgNPs coated blades showed common peaks which confirmed the successful deposition of AgNPs on cotton fabric and surgical blades. X-Ray diffraction analysis provided evidence of crystalline nature of AgNPs present on the surface of coated objects. Findings of antibacterial activities of coated objects showed that these were effective against all six tested bacterial species. Likewise, anti-biofilm formation activities of AgNPs coated objects were examined against *P. aeruginosa* and coated objects were found to be successfully inhibiting and disrupting bacterial cells. The results provide evidence that AgNPs coated objects open ways to produce reusable surgical scalpels and fabrics with excellent antibacterial and anti-biofilm formation properties for applications in clinical settings. Conclusively, current study demonstrated an advanced technique to minimize the risks of nosocomial infections using AgNPs coated materials in hospital settings. Proper sterilization of microsurgical instruments is crucial to ensure patient safety and optimize clinical outcomes. By coating instruments with AgNP, hospitals can significantly reduce infection rates, leading to faster patient recoveries and fewer complications. This approach not only improves patient outcomes but also enhances the efficiency of hospital operations, allowing more patients to be treated in a shorter time frame and reducing overall healthcare costs. In conclusion, AgNP coated materials presents promising alternative to conventional method of sterilizing and chemical disinfectants like ethanol or bleach. This approach can offer long-lasting bactericidal effects while minimizing toxicity to the human body.

Although the current study provides irrefutable evidence about potential applications of AgNPs coated objects in clinical settings, further investigations are required to test mechanism of action of AgNPs against other bacterial strains and to examine coated objects on animal models before proceeding to their clinical trials to investigate their practical efficacy. Nanomaterials have been increasingly used to tackle various environmental challenges, particularly in pollution control and remediation. However, there is growing evidence that their widespread use could also pose significant risks to the environment. Nanoparticles can persist in the environment, accumulate in soil and water, and potentially enter the food chain. Their small size allows them to penetrate biological membranes, leading to bioaccumulation in organisms. Studies have shown that certain nanomaterials can be toxic to various forms of aquatic and terrestrial life. For instance, silver nanoparticles, while effective as antibacterial agents, can also harm beneficial bacteria and aquatic organisms. To maximize the benefits of nanomaterials while minimizing their risks, it is essential to switch into green manufacturing of nanoparticles. By avoiding harmful chemicals, green synthesis methods produce nanoparticles that are less likely to be toxic to humans and the environment as the surface coatings on these AgNP's are acquired from plant extracts. Previous studies published from our lab concludes the effectiveness of biologically synthesized NPs for their safe usage in biological systems. AjNPs among them showed maximum safety and efficacy profile and consistently showed least production of reactive oxygen species, least mortality and morbidity in BALB/c mouse models compared to other nanoparticles synthesized in our lab [46]. Considering the economic aspect, these nanofabric and nano-surgical blades are cost effective as the AgNP made in this study is from plant source which is itself a safe, economical, eco-friendly, facile, and suitable approach. Moving on the coating method used to put incorporate AgNP on textiles and blades is convenient and economical as compared to other methods, however proper cost of the coatings needs to be calculated while applying the process at the commercial level.

Patents

Part of this work has been filed for patent applications Govt. of Pakistan Intellectual Property Organization The Patent Office Karachi (2019). Application No: 220/2019 for "Silver nanoparticles and PDAC coated nano-fabric" and Application No: 221/2019 for "Antibacterial silver nano-particles coated surgical blades".

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Data availability

Supplementary file is attached along with the data provided into the main manuscript also data is available from authors on reasonable request.

CRediT authorship contribution statement

Ifrah Tahir: Methodology, Formal analysis, Data curation. **Sundus Jabeen Amina:** Formal analysis. **Nasir Mahmood Ahmad:** Validation, Resources. **Hussnain Ahmed Janjua:** Writing – review & editing, Supervision, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Ifrah Tahir, Hussnain A Janjua, Naisr Mahmood Ahmed has patent #Part of this work has been filed for patent applications Govt. of Pakistan Intellectual Property Organization The Patent Office Karachi (2019). Application No: 220/2019 for Antibacterial Nano-Fabric and Application No: 221/2019 for Antibacterial Surgical Blades pending to Patents are under review. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35968.

References

[1] H.A. Khan, F.K. Baig, R. Mehboob, Nosocomial infections: epidemiology, prevention, control and surveillance, Asian Pac. J. Trop. Biomed. 7 (2017) 478–482, https://doi.org/10.1016/j.apjtb.2017.01.019.

[2] L. Zhao, H. Wang, K. Huo, L. Cui, W. Zhang, H. Ni, Y. Zhang, Z. Wu, P.K. Chu, Antibacterial nano-structured titania coating incorporated with silver nanoparticles, Biomaterials 32 (2011) 5706–5716, https://doi.org/10.1016/j.biomaterials.2011.04.040.

[3] P. Uttayarat, S. Jetawattana, P. Suwanmala, J. Eamsiri, T. Tangthong, S. Pongpat, Antimicrobial electrospun silk fibroin mats with silver nanoparticles for wound dressing application, Fibers Polym. 13 (2012) 999–1006, https://doi.org/10.1007/s12221-012-0999-6.

[4] I. Sondi, B. Salopek-Sondi, Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria, J. Colloid Interface Sci. 275 (2004) 177–182, https://doi.org/10.1016/j.jcis.2004.02.012.

[5] F. Paladini, M. Pollini, Antimicrobial silver nanoparticles for wound healing application: progress and future trends, Materials 12 (2019), https://doi.org/10.3390/ma12162540.

[6] S. Nakamura, M. Sato, Y. Sato, N. Ando, T. Takayama, M. Fujita, M. Ishihara, Synthesis and application of silver nanoparticles (Ag nps) for the prevention of infection in healthcare workers, Int. J. Mol. Sci. 20 (2019), https://doi.org/10.3390/ijms20153620.

[7] M.T. Moustafa, Removal of pathogenic bacteria from wastewater using silver nanoparticles synthesized by two fungal species, Water Sci 31 (2017) 164–176, https://doi.org/10.1016/j.wsj.2017.11.001.

[8] M.A. Shaker, M.I. Shaaban, Synthesis of silver nanoparticles with antimicrobial and anti-adherence activities against multidrug-resistant isolates from Acinetobacter baumannii, J. Taibah Univ. Med. Sci. 12 (2017) 291–297, https://doi.org/10.1016/j.jtumed.2017.02.008.

[9] C.N. Miller, N. Newall, S.E. Kapp, G. Lewin, L. Karimi, K. Carville, T. Gliddon, N.M. Santamaria, A randomized-controlled trial comparing cadexomer iodine and nanocrystalline silver on the healing of leg ulcers, Wound Repair Regen. 18 (2010) 359–367, https://doi.org/10.1111/j.1524-475X.2010.00603.x.

[10] L.G. Wasef, H.M. Shaheen, Y.S. El-Sayed, T.I.A. Shalaby, D.H. Samak, M.E. Abd El-Hack, A. Al-Owaimer, I.M. Saadeldin, A. El-mleeh, H. Ba-Awadh, A. A. Swelum, Effects of silver nanoparticles on burn wound healing in a mouse model, Biol. Trace Elem. Res. 193 (2020) 456–465, https://doi.org/10.1007/s12011-019-01729-z.

[11] X. Liu, P.Y. Lee, C.M. Ho, V.C.H. Lui, Y. Chen, C.M. Che, P.K.H. Tam, K.K.Y. Wong, Silver nanoparticles mediate differential responses in keratinocytes and fibroblasts during skin wound healing, ChemMedChem 5 (2010) 468–475, https://doi.org/10.1002/cmdc.200900502.

[12] R. Zhang, P. Lee, V.C.H. Lui, Y. Chen, X. Liu, C.N. Lok, M. To, K.W.K. Yeung, K.K.Y. Wong, Silver nanoparticles promote osteogenesis of mesenchymal stem cells and improve bone fracture healing in osteogenesis mechanism mouse model, Nanomed. Nanotechnol. Biol. Med. 11 (2015) 1949–1959, https://doi.org/10.1016/j.nano.2015.07.016.

[13] S. Zhang, X. Liu, H. Wang, J. Peng, K.K.Y. Wong, Silver nanoparticle-coated suture effectively reduces inflammation and improves mechanical strength at intestinal anastomosis in mice, J. Pediatr. Surg. 49 (2014) 606–613, https://doi.org/10.1016/j.jpedsurg.2013.12.012.

[14] M. Balamurugan, S. Saravanan, T. Soga, Coating of green-synthesized silver nanoparticles on cotton fabric, J. Coating Technol. Res. 14 (2017) 735–745, https://doi.org/10.1007/s11998-016-9894-1.

[15] S.T. Dubas, P. Kumlangdudsana, P. Potiyaraj, Layer-by-layer deposition of antimicrobial silver nanoparticles on textile fibers, Colloids Surfaces A Physicochem. Eng. Asp. 289 (2006) 105–109, https://doi.org/10.1016/j.colsurfa.2006.04.012.

[16] Ş.S. Uğur, M. Sariişik, A.H. Aktaş, M.Ç. Uçar, E. Erden, Modifying of cotton fabric surface with Nano-ZnO multilayer films by Layer-by-Layer deposition method, Nanoscale Res. Lett. 5 (2010) 1204–1210, https://doi.org/10.1007/s11671-010-9627-9.

[17] B.M. Quinn, C. Dekker, S.G. Lemay, Electrodeposition of noble metal nanoparticles on carbon nanotubes, J. Am. Chem. Soc. 127 (2005) 6146–6147, https://doi.org/10.1021/ja0508828.

[18] N.A. Resali, K.M. Hyie, M.N. Berhan, Z. Salleh, S. Kasolang, Cobalt-nickel-iron nanoparticles coated on stainless steel substrate, in: Procedia Eng., Elsevier Ltd, 2013, pp. 30–36, https://doi.org/10.1016/j.proeng.2013.12.143.

[19] M.U. Hashmi, F. Khan, N. Khalid, A.A. Shahid, A. Javed, T. Alam, N. Jalal, M.Q. Hayat, S.R. Abbas, H.A. Janjua, Hydrogels incorporated with silver nanocolloids prepared from antioxidant rich Aerva javanica as disruptive agents against burn wound infections, Colloids Surfaces A Physicochem. Eng. Asp. 529 (2017) 475–486, https://doi.org/10.1016/j.colsurfa.2017.06.036.

[20] D.M. Eby, H.R. Luckarift, G.R. Johnson, Hybrid antimicrobial enzyme and silver nanoparticle coatings for medical Instruments, ACS Appl. Mater. Interfaces 1 (2009) 1553–1560, https://doi.org/10.1021/am9002155.

[21] C.H. Ho, E.K. Odermatt, I. Berndt, J.C. Tiller, Long-term active antimicrobial coatings for surgical sutures based on silver nanoparticles and hyperbranched polylysine, J. Biomater. Sci. Polym. Ed. 24 (2013) 1589–1600, https://doi.org/10.1080/09205063.2013.782803.

[22] G. Zhang, Y. Liu, X. Gao, Y. Chen, Synthesis of silver nanoparticles and antibacterial property of silk fabrics treated by silver nanoparticles, Nanoscale Res. Lett. 9 (2014) 1–8, https://doi.org/10.1186/1556-276X-9-216.

[23] D. Arif, M.B.K. Niazi, N. Ul-Haq, M.N. Anwar, E. Hashmi, Preparation of antibacterial cotton fabric using chitosan-silver nanoparticles, Fibers Polym. 16 (2015) 1519–1526, https://doi.org/10.1007/s12221-015-5245-6.

[24] L. Chen, L. Zheng, Y. Lv, H. Liu, G. Wang, N. Ren, D. Liu, J. Wang, R.I. Boughton, Chemical assembly of silver nanoparticles on stainless steel for antimicrobial applications, Surf. Coating. Technol. 204 (2010) 3871–3875, https://doi.org/10.1016/j.surfcoat.2010.05.003.

[25] V. Mody, R. Siwale, A. Singh, H. Mody, Introduction to metallic nanoparticles, J. Pharm. BioAllied Sci. 2 (2010) 282, https://doi.org/10.4103/0975-7406.72127.

[26] A.C. Burduşel, O. Gherasim, A.M. Grumezescu, L. Mogoantă, A. Ficai, E. Andronescu, Biomedical applications of silver nanoparticles: an up-to-date overview, Nanomaterials 8 (2018), https://doi.org/10.3390/nano8090681.

[27] X. Liao, F. Yang, H. Li, P.K. So, Z. Yao, W. Xia, H. Sun, Targeting the thioredoxin reductase-thioredoxin system from Staphylococcus aureus by silver ions, Inorg. Chem. 56 (2017) 14823–14830, https://doi.org/10.1021/acs.inorgchem.7b01904.

[28] J.R. Morones, J.L. Elechiguerra, A. Camacho, K. Holt, J.B. Kouri, J.T. Ramírez, M.J. Yacaman, The bactericidal effect of silver nanoparticles, Nanotechnology 16 (2005) 2346–2353, https://doi.org/10.1088/0957-4484/16/10/059.

[29] M. Guzman, J. Dille, S. Godet, Synthesis and antibacterial activity of silver nanoparticles against gram-positive and gram-negative bacteria, Nanomed. Nanotechnol. Biol. Med. 8 (2012) 37–45, https://doi.org/10.1016/j.nano.2011.05.007.

[30] Y. Jeong, D.W. Lim, J. Choi, Assessment of size-dependent antimicrobial and cytotoxic properties of silver nanoparticles, Adv. Mater. Sci. Eng. 2014 (2014), https://doi.org/10.1155/2014/763807.

[31] X. Hong, J. Wen, X. Xiong, Y. Hu, Shape effect on the antibacterial activity of silver nanoparticles synthesized via a microwave-assisted method, Environ. Sci. Pollut. Res. 23 (2016) 4489–4497, https://doi.org/10.1007/s11356-015-5668-z.

[32] A. Abbaszadegan, Y. Ghahramani, A. Gholami, B. Hemmateenejad, S. Dorostkar, M. Nabavizadeh, H. Sharghi, The effect of charge at the surface of silver nanoparticles on antimicrobial activity against gram-positive and gram-negative bacteria: a preliminary study, J. Nanomater. 2015 (2015), https://doi.org/10.1155/2015/720654.

[33] K. Niska, N. Knap, A. Kędzia, M. Jaskiewicz, W. Kamysz, I. Inkielewicz-Stepniak, Capping agent-dependent toxicity and antimicrobial activity of silver nanoparticles: an in vitro study. concerns about potential application in dental practice, Int. J. Med. Sci. 13 (2016) 772–782, https://doi.org/10.7150/ijms.16011.

[34] S. Ashraf, M.A. Chatha, W. Ejaz, H.A. Janjua, I. Hussain, Lysozyme-coated silver nanoparticles for differentiating bacterial strains on the basis of antibacterial activity, Nanoscale Res. Lett. 9 (2014) 565, https://doi.org/10.1186/1556-276X-9-565.

[35] M. Guzman, J. Dille, S. Godet, Synthesis and antibacterial activity of silver nanoparticles against gram-positive and gram-negative bacteria, Nanomed. Nanotechnol. Biol. Med. 8 (2012) 37–45, https://doi.org/10.1016/j.nano.2011.05.007.

[36] A. Nanda, M. Saravanan, Biosynthesis of silver nanoparticles from Staphylococcus aureus and its antimicrobial activity against MRSA and MRSE, Nanomed. Nanotechnol. Biol. Med. 5 (2009) 452–456, https://doi.org/10.1016/j.nano.2009.01.012.

[37] V. Ahluwalia, J. Kumar, R. Sisodia, N.A. Shakil, S. Walia, Green synthesis of silver nanoparticles by Trichoderma harzianum and their bio-efficacy evaluation against Staphylococcus aureus and Klebsiella pneumonia, Ind. Crops Prod. 55 (2014) 202–206, https://doi.org/10.1016/j.indcrop.2014.01.026.
[38] K. Silva Santos, A. Barbosa, L. Pereira da Costa, M. Pinheiro, M. Oliveira, F. Ferreira Padilha, Silver nanocomposite biosynthesis: antibacterial activity against multidrug-resistant strains of Pseudomonas aeruginosa and acinetobacter baumannii, Molecules 21 (2016) 1255, https://doi.org/10.3390/molecules21091255.
[39] C. Krishnaraj, E.G. Jagan, S. Rajasekar, P. Selvakumar, P.T. Kalaichelvan, N. Mohan, Synthesis of silver nanoparticles using Acalypha indica leaf extracts and its antibacterial activity against water borne pathogens, Colloids Surfaces B Biointerfaces 76 (2010) 50–56, https://doi.org/10.1016/j.colsurfb.2009.10.008.
[40] X. Chen, H.J. Schluesener, Nanosilver: a nanoproduct in medical application, Toxicol. Lett. 176 (2008) 1–12, https://doi.org/10.1016/j.toxlet.2007.10.004.
[41] A.G. Femi-Adepoju, A.O. Dada, K.O. Otun, A.O. Adepoju, O.P. Fatoba, Green synthesis of silver nanoparticles using terrestrial fern (Gleichenia Pectinata (Willd.) C. Presl.): characterization and antimicrobial studies, Heliyon 5 (2019) e01543, https://doi.org/10.1016/j.heliyon.2019.e01543.
[42] P. Velmurugan, S.M. Lee, M. Cho, J.H. Park, S.K. Seo, H. Myung, K.S. Bang, B.T. Oh, Antibacterial activity of silver nanoparticle-coated fabric and leather against odor and skin infection causing bacteria, Appl. Microbiol. Biotechnol. 98 (2014) 8179–8189, https://doi.org/10.1007/s00253-014-5945-7.
[43] A. Abou-Okeil, Ag nanoparticles growing onto cotton fabric using chitosan as a template, J. Nat. Fibers 9 (2012) 61–72, https://doi.org/10.1080/15440478.2011.651841.
[44] H.Y. Lee, H.K. Park, Y.M. Lee, K. Kim, S.B. Park, A practical procedure for producing silver nanocoated fabric and its antibacterial evaluation for biomedical applications, Chem. Commun. (2007) 2959–2961, https://doi.org/10.1039/b703034g.
[45] M.K. Zahran, H.B. Ahmed, M.H. El-Rafie, Surface modification of cotton fabrics for antibacterial application by coating with AgNPs-alginate composite, Carbohydr. Polym. 108 (2014) 145–152, https://doi.org/10.1016/j.carbpol.2014.03.005.
[46] M.U. Hashmi, N. Khalid, T. Alam, R. Hanif, H.A. Janjua, Comparative safety analysis of bactericidal nano-colloids: assessment of potential functional toxicity and radical scavenging action, Colloids Surf. B Biointerfaces 184 (2019) 110508.
[47] F. Paladini, M. Pollini, Antimicrobial silver nanoparticles for wound healing application: progress and future trends, Materials 12 (16) (2019) 2540.
[48] M. Bhagat, S. Rajput, S. Arya, S. Khan, P. Lehana, Biological and electrical properties of biosynthesized silver nanoparticles, Bulletin of materials sciences 38 (2015) 1253–1258.
[49] M. Salas-Orozco, N. Niño-Martínez, G.J. Martínez-Castañón, F.T. Méndez, M.E.C. Jasso, F. Ruiz, Mechanisms of resistance to silver nanoparticles in endodontic bacteria: a literature review, J. Nanomater. (2019) 11. Article ID 7630316, https://doi.org/10.1155/2019/7630316.