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Development of Highly Stable Ofloxacin-Capped Silver Nanoparticles as a Novel Nanoplatform for Vermox Detection in Biological and Environmental Systems

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ABSTRACT

Silver nanoparticles have been synthesized using physical, chemical, and biological methods because of their distinctive physicochemical properties. Among these approaches, chemical reduction is efficient, rapid, reproducible, and cost-effective. This study synthesized environmentally friendly, stable, and economical ofloxacin-capped silver nanoparticles (OFX-AgNPs) and evaluated them as a colorimetric sensor for the selective detection of Vermox in biological and environmental samples. The nanoparticles were characterized using UV-visible spectroscopy, X-ray diffraction (XRD), dynamic light scattering (DLS), zeta-potential analysis, and transmission electron microscopy (TEM) to assess their optical properties, structure, particle size, morphology, and stability. The OFX-AgNPs were uniformly dispersed, spherical, narrowly distributed in size, and highly stable. UV-visible spectroscopy confirmed the interaction between ofloxacin and the nanoparticle surface, while TEM analysis showed a uniform morphology and size distribution. The OFX-AgNPs exhibited high sensitivity and selectivity for Vermox, demonstrating their potential as an efficient colorimetric probe. Vermox was detected in wastewater, urine, and blood samples through a distinct optical response. The chemical reduction method was selected because of its simplicity, rapid synthesis, cost-effectiveness, and reproducibility compared with biological and physical methods.

1. Introduction

In recent years, nanotechnology has attracted considerable attention because of its applications across numerous areas of modern science and technology. It offers innovative solutions in environmental science, medicine, materials engineering, and other fields. The ability to manipulate materials at the nanoscale has enabled researchers to develop materials with distinctive properties. Metal nanoparticles are particularly important because of their optical, electronic, and catalytic characteristics [1,2,12]. Silver nanoparticles have attracted substantial interest because of their thermal, chemical, optical, magnetic, catalytic, and electrical properties [4,31]. They also exhibit a high surface-area-to-volume ratio and quantum-confinement effects [27,33]. Their behavior depends on particle size, shape, color, surface chemistry, the surrounding environment, and the degree of aggregation [10,25], enabling applications in

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environmental monitoring, biological sciences, and drug delivery [6,18]. Like gold nanoparticles, silver nanoparticles interact strongly with light and exhibit pronounced localized surface plasmon resonance (LSPR) and tunable surface chemistry. Several colorimetric methods based on silver and gold nanoparticles have recently been proposed; however, silver nanoparticles are often preferred for detecting heavy metals, drugs, and biomolecules because of their distinctive optical response [17,19]. Their plasmonic behavior depends strongly on aggregation, morphology, particle size, and the surrounding medium [10,20,22,28,34]. Consequently, these nanoparticles are promising materials for controlled drug delivery, optical fibers, sensors, and biological and environmental detection [7,15,23]. They have also been investigated for tissue repair and antibacterial applications [21,23]. Because of their broad utility, extensive research has focused on nanoparticle-based applications [20,24]. Depending on the synthesis conditions, nanoparticles may appear black, purple, blue, or dark red and can be monitored visually or by UV-visible spectroscopy. They can be synthesized rapidly under the influence of solvents, stabilizers, and reducing agents [13,16].

Antibiotics have increasingly been used to stabilize and functionalize metal nanoparticles. Their functional groups can bind strongly to nanoparticle surfaces through electrostatic interactions, coordination, or hydrogen bonding. This interaction improves nanoparticle stability and provides selective binding sites for target molecules. In this study, ofloxacin, a fluoroquinolone antibiotic, was used as a capping and functionalizing agent to stabilize AgNPs and enhance the detection of Vermox in samples [33,42]. Its molecular structure contains fluorinated aromatic groups, carbonyl and carboxyl groups, and hydrogen-bonding sites [31,37,43], which promote charge interactions between ofloxacin and silver nanoparticles and produce a highly stable colloidal system. The molecular structure of ofloxacin also enabled selective colorimetric detection of Vermox, making it a promising capping agent for sensing applications. Vermox was selectively detected in biological and environmental samples through a color change visible to the naked eye.

Vermox (mebendazole) is widely prescribed for intestinal parasitic infections. After use, a portion of the drug may enter the environment through excretion or improper disposal. Monitoring Vermox in biological fluids and wastewater is therefore important for public and environmental health [27,28]. Conventional methods for detecting drugs such as Vermox include chromatography and spectroscopy; however, these methods can be time-consuming and costly and often require sophisticated instrumentation. Such limitations restrict rapid, field-based sample analysis [26,28]. Colorimetric sensors based on silver nanoparticles offer a promising alternative because the resulting color changes can be observed without instrumentation. This optical behavior makes antibiotic-assisted silver nanoparticles valuable for analytical applications [37,39,40]. Overall, this study contributes to nanotechnology by demonstrating highly effective antibiotic-functionalized silver nanoparticles. The findings may support the development of next-generation sensing systems for pharmaceutical monitoring, environmental analysis, and healthcare diagnostics.

2. Experimental

2.1 Materials And Chemicals

Silver nitrate (AgNO3; Merck, 99.9%), sodium hydroxide (NaOH; Merck, 99.9%), and other analytical-grade reagents with purities greater than 99% were used throughout the study. Ofloxacin was obtained from Sigma-Aldrich. All chemicals were used as received without further purification. Fresh stock and working solutions, biological and environmental samples, and solvents were prepared according to standard laboratory protocols. Milli-Q water was used throughout to ensure high purity and minimize contamination.

2.2 Synthesis Of OFX-AgNPs By Chemical Reduction Method

Ofloxacin-coated silver nanoparticles were synthesized using a conventional chemical reduction method, which is economical, reliable, and reproducible. This method was selected because it offers rapid reaction kinetics and control over nanoparticle size, morphology, and colloidal stability. Aqueous solutions of AgNO3 and NaOH were prepared using Milli-Q water. First, 25 mL of 0.1 M AgNO3 was transferred to a clean reaction vessel and stirred continuously to ensure homogeneity. Subsequently, 75 mL of 0.01 M NaOH was added carefully under continuous stirring. The reaction mixture was stirred for 12 min to ensure sufficient reduction and interaction. Approximately 7 mL of 1% (w/w) ofloxacin was then added under continuous magnetic stirring. Adsorption of ofloxacin onto the nanoparticle surface formed a stabilizing layer that improved colloidal stability. The mixture was stirred for an additional 20 min to ensure complete interaction between ofloxacin and the nanoparticles. A yellowish-brown color developed, providing preliminary visual confirmation of silver nanoparticle formation.

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After stirring, the reaction mixture was aged for 3 days under ambient laboratory conditions to allow complete nanoparticle growth and attachment of the capping agent. This step promoted thermodynamic stability and improved dispersion. The OFX-AgNPs were then purified by repeated washing and centrifugation to remove unreacted reagents, ionic species, and excess ofloxacin. Finally, the nanoparticles were resuspended in 50 mL of Milli-Q water to obtain a stable colloidal dispersion. Unless otherwise specified, all experiments were conducted at room temperature under standard laboratory conditions.

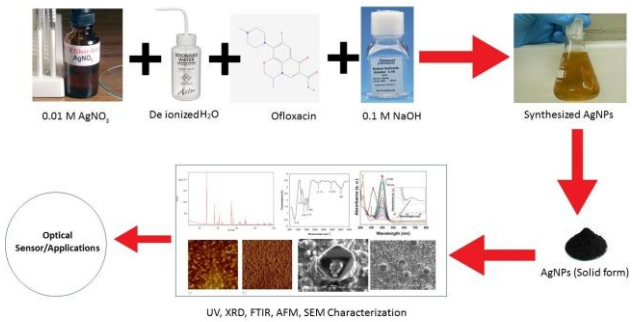

Fig. 1. Illustration Of The Synthesis Process Of Ofloxacin-Assisted AgNPs

2.3 Characterization Techniques

Several techniques were used to evaluate the properties of the ofloxacin-capped silver nanoparticles, including X-ray diffraction (XRD), UV-visible spectroscopy, dynamic light scattering (DLS), zeta-potential analysis, and transmission electron microscopy (TEM). Collectively, these methods provided information on nanoparticle formation, optical behavior, structure, particle size, morphology, and colloidal stability.

2.4 Sample Preparation For Characterization Techniques

Careful sample preparation was performed to ensure reliable characterization of the synthesized nanoparticles. For XRD, TEM, and DLS analyses, OFX-AgNP samples were prepared using a heat-and-wash procedure. Briefly, 50 mL of the OFX-AgNP suspension was transferred to a glass container and heated at 100 °C for 1 h to evaporate water and concentrate the nanoparticles. During heating, the suspension changed from yellow to dark black. The resulting material was washed three times with ethanol and deionized water and then oven-dried for 20 min. Complete drying was required to obtain accurate XRD patterns for evaluating phase composition and crystallinity. The same purified material was used for TEM analysis. A drop of the purified nanoparticle suspension was deposited onto a carbon-coated copper grid and dried under laboratory conditions. For DLS analysis, nanoparticles obtained after the heat-and-wash process were redispersed in deionized water. In contrast, UV-visible spectroscopy and zeta-potential analyses were conducted directly on the liquid OFX-AgNP suspension without drying or powder preparation.

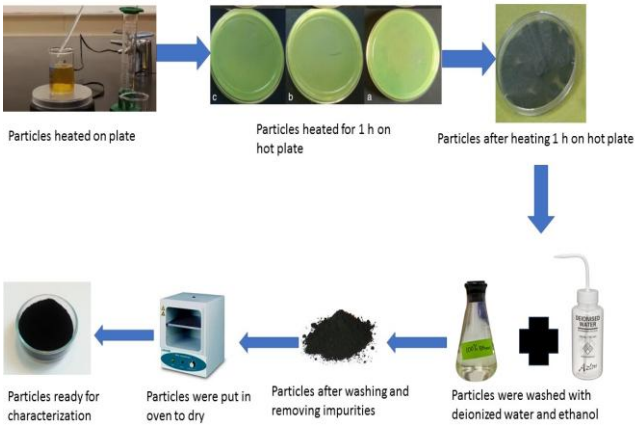

Fig. 2. Process Of Sample Preparation Of OFX-AgNPs For Characterization

2.5 Collection Of Biological And Environmental Samples

Biological specimens were collected from patients attending Civil Hospital Hyderabad and Jamshoro Hospital, Pakistan. The specimens included urine and blood samples from patients with parasitic worm infections, including roundworm and hookworm infections. Blood serum and urine samples were collected in appropriate glass tubes. Five milliliters of urine and 5 mL of blood were obtained from each patient and placed in capped test tubes. The participants comprised equal proportions of males and females. Environmental samples were collected from the wastewater of a pharmaceutical company in Jamshoro, the Indus River, and a lake in Kotri, Sindh, Pakistan.

2.6 Preparation Of Biological And Environmental Samples

The test tube containing 5 mL of blood was kept upright for 30 min to allow clot formation and was then centrifuged at 2200-2500 rpm for 15 min. The resulting serum was carefully transferred to a labeled tube using a pipette without disturbing the cellular fraction and was refrigerated until analysis.

Urine samples were diluted at a 70:30 ratio of water to urine. The mixture was centrifuged at 1500 rpm for 60 s, and the supernatant was labeled and refrigerated until analysis.

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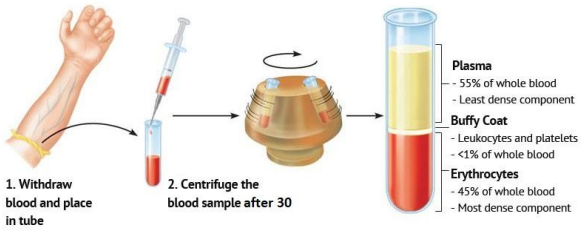

Fig. 3. Preparation Of Serum From Blood For Experimental Analysis

3. Results and Discussion

The proposed OFX-AgNP system enabled colorimetric detection of Vermox through a visible color change from yellow to white, allowing observation without advanced instrumentation. This feature supports rapid on-site applications in resource-limited settings. The UV-visible absorption spectrum of the OFX-AgNPs showed a maximum absorption peak at 405 nm with a peak width of approximately 18 nm, as shown in Fig. 4. The optical spectrum confirmed nanoparticle formation in the presence of the capping agent. Dynamic light scattering analysis provided the hydrodynamic cluster size, while zeta-potential analysis yielded a value of -8.9 mV. Although the magnitude of the zeta potential was relatively low, steric stabilization by ofloxacin molecules adsorbed on the nanoparticle surface was considered the primary contributor to colloidal stability. This interpretation was supported by the UV-visible and TEM results, which indicated stability for up to 3 months. No substantial impurities or agglomeration were observed. TEM analysis showed spherical ofloxacin-capped silver nanoparticles with an average diameter of 17 nm. Nanoparticle stability was evaluated over 3 months using zeta-potential measurements, as shown in Fig. 5 [36,40].

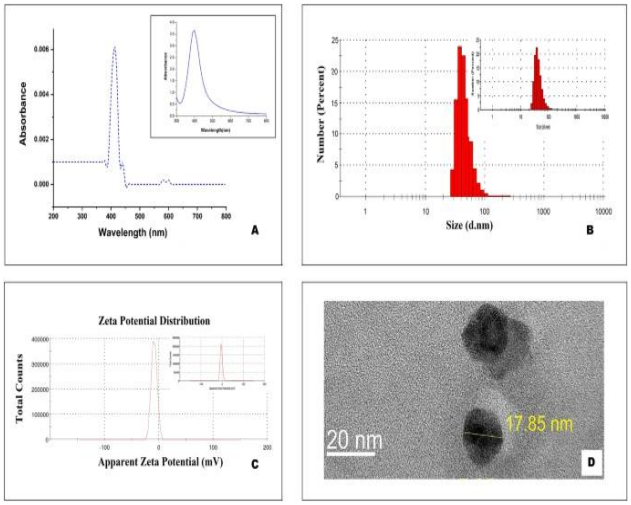

Fig. 4. Characterization Of OFX-AgNPs: (A) UV-Visible Absorption Spectrum, (B) Cluster Size Obtained By DLS, (C) Zeta Potential, And (D) TEM Image

After 3 months, the maximum UV-visible absorption peak of the OFX-AgNPs was approximately 410 nm, with a peak width of 20 nm (Fig. 5). Hydrogen bonding and electrostatic interactions between the functional groups of ofloxacin and the silver nanoparticles prevented aggregation and enhanced stability. The small shift in the absorption peak indicated that the nanoparticles remained stable. Zeta-potential analysis yielded a value of -10.9 mV, while TEM images obtained after 3 months showed spherical nanoparticles with an average diameter of 12.9 nm.

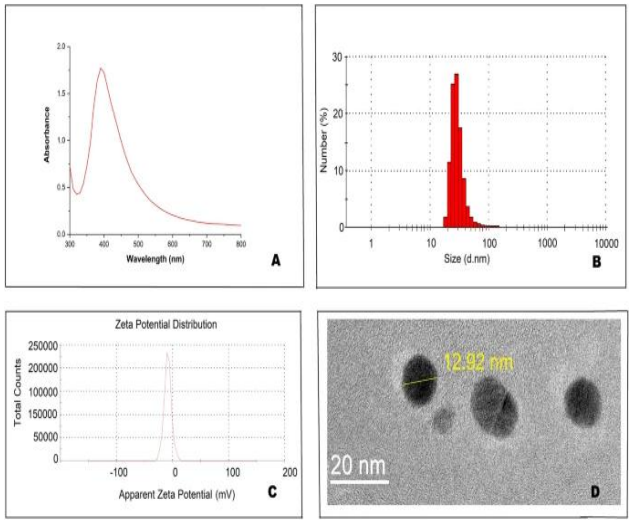

Fig. 5. Characterization Of OFX-AgNPs/Vermox: (A) UV-Visible Absorption Spectrum, (B) Cluster Size Obtained By DLS, (C) Zeta Potential, And (D) TEM Image

4. Applications in Biological and Environmental Samples

The presence of Vermox in biological and environmental samples was evaluated using the synthesized OFX-AgNPs. UV-visible spectroscopy was used to assess the colorimetric response of the nanoparticles. The OFX-AgNPs detected Vermox through a visible color change and corresponding changes in their optical properties. Compared with the other medicines and antibiotics tested, the OFX-AgNPs exhibited a strong and selective response to Vermox. Addition of a small volume of Vermox solution changed the nanoparticle suspension from yellow to white, demonstrating its potential as a colorimetric sensor. Biological and environmental samples spiked with Vermox produced the same color change and a hyperchromic shift in the UV-visible absorption band. Other drugs tested under identical conditions produced no substantial response, supporting the selectivity of the method.

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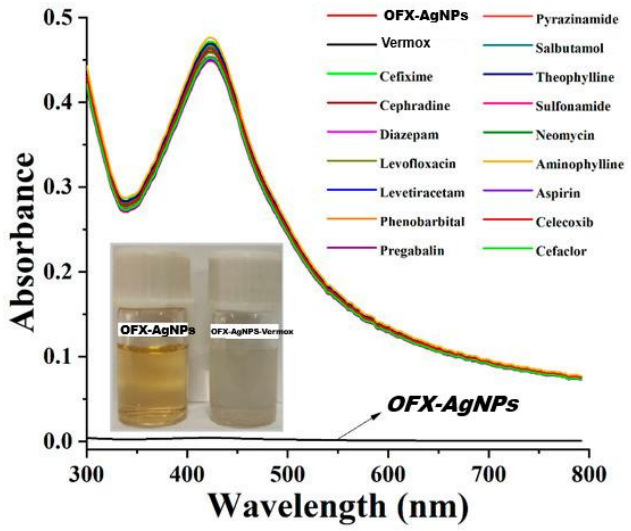

Fig. 6. UV-Visible Spectra Of OFX-AgNPs Before And After Individual Addition Of Vermox And Other Drugs

Conclusion

This study successfully synthesized highly stable, ofloxacin-assisted silver nanoparticles. The resulting OFX-AgNPs exhibited properties suitable for the selective detection of Vermox in biological and environmental samples. The detection response was specific and could be observed with the naked eye, demonstrating the potential of OFX-AgNPs as a simple colorimetric sensing platform.

Future Study

Future work should include in vitro and in vivo evaluation of the nanoparticles. Double capping of OFX-AgNPs with suitable polymers may also improve their functionality, stability, and applicability to real samples.

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