

Antibacterial properties of silver-containing composite materials based on silica and polylactic acid

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Antimicrobial resistance is a critical global challenge, demanding new strategies for effective treatment. The rise of multidrug-resistant bacteria highlights the urgent need for alternative approaches to combat resistance.

This study aimed to investigate composite materials containing silver nanoparticles (AgNPs) impregnated on silica (SiO₂) and incorporated into a polylactic acid (PLA) matrix. The nanoscale form of silver enhances its biocidal efficiency by increasing surface area and reactivity. The combination of AgNPs with SiO₂ ensures uniform nanoparticle distribution, preventing aggregation and improving composite stability. Given the physicochemical properties of silica – particularly its large surface area and adjustable pore structure – it was selected as a carrier for silver nanoparticles in this study. The addition of polylactic acid was intended to enhance the material's biocompatibility while reducing the toxicity of silver.

Silver nanoparticles were synthesized on silica via impregnation, followed by heat treatment and in situ polymerization of L-lactide to obtain a composite material based on polylactic acid and silica. A comparative analysis of composites containing silver nanoparticles (SiO₂-Ag) and those modified with polylactide (SiO₂-Ag-PLA) was conducted using a range of physicochemical methods. The modification of the silica surface and the formation of composites were confirmed through infrared spectroscopy. The crystal structure of the nanoparticles was determined by X-ray

diffraction analysis, while thermogravimetry was used to assess the thermal stability of the composites.

The zeta potential of SiO₂-Ag and SiO₂-Ag-PLA nanocomposites was evaluated in solution. SiO₂-Ag showed more negative values, particularly in alkaline conditions, indicating higher colloidal stability. In contrast, SiO₂-Ag-PLA exhibited less negative zeta potential at low pH, suggesting increased aggregation. The absence of an isoelectric point for SiO₂-Ag and the reduced negative charge of SiO₂-Ag-PLA at pH < 4 suggest ion adsorption or surface charge modifications due to partial functionalization. Incomplete polylactide coverage and surface silver nanoparticles likely contribute to these changes. Both systems may have limited stability in alkaline conditions, with SiO₂-Ag-PLA being more prone to aggregation in acidic environments.

The antibacterial activity of the nanocomposites was assessed against gram-positive (*Staphylococcus aureus*) and gram-negative (*Escherichia coli*, *Klebsiella pneumoniae*) bacteria with varying antibiotic sensitivities using the microdilution method in a 96-well plate with resazurin. The results demonstrated that SiO₂-Ag was effective against all tested bacterial strains. Furthermore, no significant differences in the minimum inhibitory concentration (MIC) of SiO₂-Ag were observed among the gram-negative bacteria. However, in *Staphylococcus aureus*, the MIC for the antibiotic-resistant strain was twice as high as for the antibiotic-sensitive strain.

Modification of the nanocomposites with polylactic acid resulted in a reduction of the antibacterial activity of SiO₂-Ag-PLA against all studied strains. However, no clear correlation was found between the taxonomic classification of these bacteria, their antibiotic sensitivity, and their response to SiO₂-Ag-PLA.

The findings of this study confirm the potential of the synthesized composites for use in medical coatings and antibacterial materials. The incorporation of polylactic acid enhances biocompatibility and biodegradability, broadening the scope of their practical applications.

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