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Boosting antimicrobial efficacy using polymeric nanoparticles

Rodrigo Cé

Biomedical Sciences Department, Centro Universitário Avantis - UNIAVAN, Brazil

ABSTRACT

Bacterial infections are a major threat in medicine, often causing significant morbidity and mortality. Despite the effectiveness of antibiotics, the rise of antibiotic-resistant strains presents a pressing challenge worsened by misuse. Antibiotics target essential cellular processes to combat microorganisms, including bacteria, fungi, and viruses. Nanoparticles offer promising alternatives with customizable properties for targeted therapy, employing unique antibacterial mechanisms. Carbon-based, metal-based, polymeric, and lipid-core nanocapsules show potential in inhibiting bacterial growth and curbing resistance. Lipid-core nanocapsules are versatile platforms for drug delivery, enhancing antibacterial activity and altering interactions with bacterial cells. In this study, we explore the efficacy of lipid-core nanocapsules in combating antibiotic resistance and improving patient outcomes, paving the way for advancements in modern medicine.

KEYWORDS

Nanocapsules; Anti-bacterial agents; Bacterial infections; Drug resistance; Morbidity

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Introduction

In recent years, bacterial illnesses have emerged as a significant cause of fatalities and persistent infections. Although research has shown that the overuse of these medications has contributed to the formation of antibiotic-resistant forms of bacteria, antibiotics have long been the preferred treatment for bacterial illnesses due to their efficiency and accessibility [1,2]. Different classes and groupings of antibiotics have been created in an effort to address this problem. However, drug resistance is directly related to antibiotic misuse, which increases death rates and lengthens hospital admissions [3,4]. Microorganisms like bacteria, fungi, and viruses are eliminated by antimicrobial agents, which include antibiotics.

Currently, antibiotics' three primary targets are translation machinery, cell wall construction, and DNA replication. Bacteria may, however, acquire resistance to these treatments [5-7]. Since they can stop germ development and lessen symptoms, antibiotics are frequently used as the first line of defense in the treatment of infections [8].

Compared to conventional antimicrobial chemicals, using nanoparticles as antimicrobial agents provides a number of potential advantages. For instance, nanoparticles can be engineered to have particular characteristics that increase their efficacy in eradicating or preventing the growth of bacteria.

By adding ligands, which bind to receptors on the surface of microorganisms and improve the treatment's efficacy, nanoparticles can also be directed to particular cells or tissues [5,9,10]. The creation of nanoparticles with antibacterial capabilities can stop the development of antibiotic resistance. Pharmaceutical nanotechnology is a field that is quickly expanding. Nanoparticles are materials with at least one dimension between 1 and 100 nm [11,12]. They are efficient antibacterial delivery agents because of their high surface area-to-volume ratio [13]. Nanoparticles have distinctive properties, including form, size, charge, reactivity, and surface area to mass ratio, which can be applied in a variety of sectors, including medical science [10,13].

Researchers have investigated the potential of using nanoparticles to stop the growth of both Gram-positive and Gram-negative bacteria. Nanoparticles' antibacterial effects are related to non-oxidative processes, the development of oxidative stress, and the release of metal ions [14-16]. In addition, the penetration of the cell membrane, disruption of the cell membrane, and production of reactive oxygen species are frequently the causes of the impacts of nanoparticles on bacteria [3,5]. Nanoparticle-based therapies have the potential to improve bacterial growth inhibition and reduce resistance development [17]. There has been evidence of promising antibacterial action in a number of nanoscale systems, including carbon and metal, polymers, dendrimers, nanoemulsions, nanocomposites, liposomes, micelles, and polymeric nanocapsules [3,18-20]. Furthermore, lipid-core nanocapsules, a particular class of polymeric nanoparticles made of poly(e-caprolactone), sorbitan monostearate, medium-chain triglyceride, and polysorbate 80, have been researched as antibacterial agents to treat infections [20-22].

In the realm of pharmaceutical nanotechnology, research on the use of nanoparticles to fight diseases and avoid microbial drug resistance is expanding. Effective bacterial growth inhibition is made possible by the capacity of nanoparticles to engage with diverse bacterial cell components through a variety of factors, including van der Waals forces, electrostatic attraction, hydrophobic contacts, and receptor ligand interactions [23-26]. Nanoparticles have been demonstrated to cause oxidative stress, alterations in cell membrane permeability, enzymatic inhibition, and other processes, according to studies [27,28]. Non-oxidative processes, oxidative stress, and metal ion release are a few of these mechanisms [29-31].

***Correspondence:** Prof. Dr. Rodrigo Cé, Biomedical Sciences Department, Centro Universitário Avantis - UNIAVAN, Brazil, e-mail: rodrigoce@hotmail.com/ rodrigoce@uniavan.edu.br

Gram-positive or Gram-negative bacteria may be more resistant to antibacterial nanoparticles than others [32]. Testing a bacteria's susceptibility to nanoparticles by bacterial plating is possible. A possible method for combating medication resistance is the creation of novel nanoparticles with antibacterial capabilities [33,34].

The non-volatile, chemically stable structure of polymeric nanoparticles as antibacterial agents binds to target surfaces while avoiding biological membranes like the skin [35]. Polycationic antimicrobials, such as quaternary ammonium compounds that act against both Gram-positive and Gram-negative bacteria, are very efficient because they have a high surface density of active groups [35,36].

Five clinical strains of *Staphylococcus aureus* that were resistant to a number of antibiotics, including ciprofloxacin, clindamycin, erythromycin, gentamicin, oxacillin, and penicillin G, were successfully inhibited from growing in a study by Cé et al. using lipid-core nanocapsules. Six strains of the filamentous *fungus Aspergillus fumigatus, Aspergillus flavus*, and *Aspergillus niger* were likewise unable to grow as a result of these combinations. In both sets of tests, dapsone's growth-inhibitory action was enhanced by its encapsulation in nanoparticles. Furthermore, the addition of chitosan to the formulations enhanced their ability to combat *Staphylococcus aureus*, whereas the antifungal effects of the drug's nanoencapsulation were more clearly felt [37].

Fusidic acid can be added to lipid-core nanocapsules to increase their in vitro antibacterial activity against strains of *Staphylococcus aureus, Enterococcus faecalis*, and *Staphylococcus epidermidis*, according to a different study by Cé et al. Additionally, measurements of mean diameter, polydispersity index, and zeta potential were used to assess how the nanocapsules interacted with bacteria. In this case, the stretching mode of the C double bond O (amide I), or stretching mode (C=O) of the COO group in *S. aureus*, the stretching mode of the COO group in *E. faecalis*, the stretching mode of the C-O-Cester bonds in *S. aureus*, and the stretching mode of the C double bond O (amide I) probably related to the formation of aggregates after exposure of the formulations to the bacteria were observed in infrared fusidic acid was enclosed in lipid-core nanocapsules, coated with or without chitosan, which altered the drug's biological behavior and enhanced its effectiveness in vitro against strains of *S. aureus*, *E. faecalis*, and *S. epidermidis* [20].

The production of polymeric nanocapsules for preventing microbial growth using self-assembly processes will probably remain a promising method in the future. These nanocapsules can be customized in terms of size and structure to maximize performance. They are made to encapsulate and deliver antimicrobial drugs to target bacteria. Self-assembly methods are anticipated to become more effective and scalable with technological advancements, enabling the manufacturing of more nanocapsules at a reduced cost.

Conclusions

Polymeric nanocapsules' capacity to specifically target microbial cells while preserving healthy cells is one of its main benefits. This is especially crucial in light of the growth in antimicrobial resistance, which has created a demand for more specialized treatments that work well. Since the antimicrobial drugs may be given directly to the site of infection in a regulated and sustained manner using nanocapsules, it may be able to lessen the likelihood that resistance would develop.

Disclosure statement

No potential conflict of interest was reported by the authors.

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