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Updates for Silver Nanoparticles' Applications in Medical Field: A Review Article

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ABSTRACT

Nanoparticles are now at the leading center of attention in scientific investigations and applications when it comes to clinical practices, mainly within the scope of nanomedicine. They possess physicochemical properties that allow them to perform biologically in ways traditional materials would never achieve; hence, they enable useful advancements in drug delivery, diagnostics, and therapeutic strategies. For instance, Silver nanoparticles (AgNPs) attracted tremendous interest recently within the medical field owing to their unique properties that enable them to be used applicatively within diagnostics and therapeutics. Recent literature has placed a significant emphasis on Silver nanoparticles (AgNPs), primarily resulting from their new properties and huge potential applications in various biomedical fields, especially for cancer treatment. The current paper presents an overview of existing research concerning nanoparticles of all sorts, their applications, and technological advancement driven based on improving efficacy within the realm of medicine. It also compiles current findings on the preparation, modes of action, uses, and safety issues of AgNPs, focusing mainly on their role in fighting multidrug-resistant infections, cancer therapy, and possible toxicity.

KEYWORDS

Silver nanoparticles, medical field, cancer, antimicrobial

INTRODUCTION

Nano-sized particles (Nanoparticles) are of great value to the field of medical physics due to new properties that arise at this size. The most important physically is their enhanced penetration capacity due to their very small size (1–100 nm) and increased uptake by cells, an essential feature for targeted drug delivery and imaging. A large surface area to volume ratio allows for the efficient attachment of therapeutic agents or imaging markers. Chemically, them can be designed for controlled reactivity, compatibility with biological systems, and functionalization with ligands or antibodies for selective binding to diseased tissues or cells, Etc. All these make them enhance contrast in image techniques like MRI (Magnetic Resonance Imaging) and CT scan (Computed Tomography) provide more specific cancer therapy with fewer side effects through restricted off-target interactions (Prabhu et al., 2012). Nanoparticles have come to the limelight as a primary interest in scientific investigation and with applications, particularly in the clinical aspect of nanomedicine. Their unique physicochemical properties equip them to make biological interactions that conventional materials would not allow possible, thus leading to further enhancement in delivery systems for drugs and diagnostic as well as therapeutic strategies (Mitchell et al., 2020). Toy et al. (2014) further enlightened the relationship between shape and biological aspects by pointing out how shape influences biodistribution and targeting aspects of nanoparticles, especially when used in cancer therapies. This places an engineer's need for making nanoparticles applicable to specific therapeutics, thus leading toward a research potentiality directed at optimizing shape for better targeting efficacy .

AgNPs can be synthesized by any of the three methods; chemical, physical, and biological approaches. Current trends reflect the preference for biological synthesis of AgNPs as a safer method, eco-friendly compared to the chemicals applied in traditional synthesis. Use of plant extracts not only makes it cost-effective but also brings it into alignment with sustainability in nanotechnology (Chung et al., 2016; Roy et al., 2019). In addition, characterization of green-synthesized AgNPs has revealed theirs potent antimicrobial activity which is paramount in medical applications (Gudikandula & Maringanti, 2016; Khorrami et al., 2018).

Even with major leaps in nanoparticle tech, lots of learning gaps stay. Like, while we looked at how AgNPs and chitosan nanoparticles work, we need bigger studies on their long-term biodistribution and possible toxicity in real-world settings. Plus, while we talked about different ways to make nanoparticles, there's no standard protocol that could make studies more reproducible and comparable (Austin et al., 2014) .

Though the present literature sets forth the potential of AgNPs in a plethora of medical applications, gaps in knowledge make it imperative to conduct further studies. First, long-term studies on the biocompatibility and toxicity of AgNPs in clinical applications need to be undertaken for safety standardization. Other paramount research interests should be the environmental impacts—accumulation and effects—of AgNPs as their application in medicine continues (Ealias & Saravanakumar, 2017). More comprehensive studies on the mechanisms through which AgNPs exert their effects on different pathogens would provide insights into using them more effectively as therapeutic agents. Other research that should be prioritized is that which applies to developing AgNPs to use them specifically as targeted therapeutic agents—for example, with cancer therapy .

Finally, the incorporation of green synthetic approaches with prompt advanced characterization may lead to newer formulations of AgNPs having safer and more efficacious profiles. Though applications of AgNPs are attractive, yet in most cases, the cytotoxicity and inflammatory effects in human cells induced by them have been reported as major challenges (Prabhu & Poulose, 2012; Liao et al., 2019). Studies demonstrated that research should be continuously updated to ensure safety aspects when using AgNPs, especially their effects on human health and the environment in the long run (Xu et al., 2020). A good understanding of the biological interactions of AgNPs is critically important in designing safe therapeutic strategies and ensuring their proper use within medical settings.

Silver nanoparticles synthesis methods also bear important roles in their anticancer efficacy. Gherasim et al., (2020) informed that green synthesis methods have brought forth AgNPs with good characteristics and yet cytotoxic to most cancer cell lines including prostate cancer cells (Gherasim et al., 2020). Characterization of these nanoparticles is a prerequisite for understanding their efficacy and safety profiles; obviously, the two most important aspects needed for their transition from laboratory settings to clinical applications (Hussain et al., 2015).

The present writings bring out the rather optimistic possibilities for the use of AgNPs in numerous applications within medicine. Yet, many lacunae in knowledge demand further probing. The long-term aspects of biocompatibility and toxicity of AgNPs in clinical applications need exhaustive study to develop safety benchmarks. Another important aspect is studying the environmental impact of AgNPs, particularly their accumulation and effect on ecosystems as their medical applications get established. (Ferdous & Nemmar, 2020). More research regarding the mechanisms of action of AgNPs against different pathogens can bring more insight into their optimal use therapeutically. Studies on designing AgNPs with more specificity for targeted therapy—mainly for cancer treatment—are equally required. Lastly, linking green synthesis routes to advanced characterization may lead to new formulations of AgNPs having better profiles in safety and efficacy.. (Castillo-Henríquez et al., 2020; Garibo et al., 2020).

Types of nanoparticles

Among them, silver nanoparticles are the most popular since their antibacterial property is well established in the literature. Siddiqi et al. (2018) reviewed both archaic and modern applications of AgNPs with emphasis on their antimicrobial effects which are critical in healthcare and agriculture applications. Bruna et al., 2021 further emphasized mechanisms of actions against multi-drug resistant bacterial strains; hence, highlighting the importance of AgNPs in recent healthcare challenges. For non-parenteral drug administration, chitosan-based nanoparticles have promising attributes due to viable bio-compatibility as well as muco-adhesiveness. Mohammed et al., 2017 explained novelties in synthesis and application of chitosan nanoparticles based on which possible sustained release and targeted therapeutic applications can be achieved. Ahmed & Aljaeid, 2016 work tends to prove such claims by presenting preparation and characterization works related to derivatives of chitosan emphasizing their role in enhanced drug delivery systems. Mesoporous silica nanoparticles (MSNs) are an important evolution in the trend of drug delivery technologies. Narayan et al. (2018) reviews the advantages of MSNs mainly in terms of their possible payload capacity with a range of therapeutic agents and possibilities toward overcoming drug resistance. This brings to light just how polymorphic the realm of nanoparticles is within biomedicine to further reinforce this general theme driving enhanced delivery mechanisms for drugs. Lohcharoenkal et al. (2014) discuss potential applications for protein nanoparticles as carriers for drug delivery, placing them squarely within the therapeutic context and current innovation trends in nanoparticle technology.

Although the results in the anticancer applications of silver nanoparticles seem promising, it is imperative to resolve much of the challenges that will ease their clinical translation. For instance, safety issues as well as the biodistribution and pharmacokinetics of AgNPs need to be more elaborately studied (Bayda et al., 2017; Mathur et al., 2018). Potential toxicity towards healthy cells and the long-term effects of AgNPs in biological systems should also be major considerations for extensive studies to enable safe applications in cancer therapies. Therefore, further studies should involve synthesis optimization focused on making these particles more efficient therapeutically while being less toxic (Stark et al., 2015). More studies should also evaluate combination treatments involving AgNPs and current anticancer drugs. This treatment could be synergistic toward better treatment outcomes. One such approach shall be through multifunctional nanocomposites based on peptides for targeted delivery which may lead to improved precision in cancer targeting. (Matteis et al., 2018).

Medical Application of silver nanoparticles

Understanding how nanoparticles interact biologically is important for their correct use in the field of medicine. Oh and Park (2014) discussendo- and exocytosis mechanisms for functionalized nanoparticles that play key roles in their therapeutic effectiveness. Well documented is nanoparticle size, shape, and surface chemistry for efficacy enhancement, hence the need to further explore these parameters.

Antimicrobial Properties of AgNPs

AgNPs have powerful antimicrobial properties against a wide variety of pathogens, including multidrug-resistant strains. Size, shape, and surface characteristics dictate their efficacy (Dakal et al., 2016). Antimicrobial activity may result from the generation of ROS by AgNPs, disruption of the membrane in target cells, and interference with bacterial metabolism (Bruna et al., 2021; Xu et al., 2020). Based on these mechanisms and considering the resistance escalation to antibiotics, it would be assumed that AgNPs could be alternative antimicrobial agents. Moreover, AgNPs showed synergy with conventional antibiotics whose application reduced dosages and side effects (Bruna et al., 2021). This synergy is opening new methodologies especially for infections caused by resistant strains; thus existing protocols can be improved. (Yuan et al., 2017).

Chemotherapy of Cancer

Besides their antimicrobial applications, AgNPs can be further applied in cancer therapy. The cytotoxic selective action of AgNPs towards cancer cells but not to the normal cells is an attractive advantage since it makes them possible candidates for targeted therapies (Khorrami et al., 2018). The possibility of using AgNPs as carriers for drug delivery systems makes their application in personalized medicine more plausible (Burdușel et al., 2018). Thus, scientists are investigating how to apply AgNPs in anticancer therapy not only to make treatment more effective but also to improve patient outcomes(Jeyaraj et al., 2013).

It was evidenced that the shapes of AgNPs play an important role in the cytotoxicity induced on cancer cells. The main mechanisms are through oxidative stress and apoptosis (Gomathi et al., 2020). For example, as reported by Gomathi et al. (2020), silver nanoparticles synthesized by Tamarindus indica fruit shell-plant extract exhibited much anticancer activity against MCF-7 human breast cancer cell lines. Simply put, these nanoparticles facilitate inhibition of the growth of cancer cells and induction of apoptosis in malignant cells. Another study carried out by Yuan et al., (2018) revealed synergistic treatment between camptothecin and AgNPs for HeLa cell oxidative stress, and apoptotic enhancement responses which also indicate their potential role as adjuvants in cancer therapy. (Yuan et al., 2018). Meanwhile, Hwang et al. (2012) noted the above findings when they said the generation of reactive oxygen species (ROS) by silver nanoparticles could be instrumental in their mechanism of action leading to increased oxidative stress within the cancerous cells. This further strengthens the idea that AgNPs do not just play their role as direct cytotoxic agents but may also turn out to be better enhancers of existing chemotherapy by overcoming drug resistance (Hwang et al., 2012).

AgNPs may have direct cytotoxic effects. However, their exploitation in anticancer drug delivery is being considered. Bayda et al. (2017) argued that engineering inorganic nanoparticles, such as silver ones, for targeted delivery could result in more effective treatments with fewer side effects (Bayda et al., 2017). This also applies to improving bioavailability as Gomes et al. (2021) described the dual role of AgNPs in therapy and as a vector (Gomes et al., 2021). The work mentioned above provides an outline of the benefits of utilizing precisely synthesized AgNPs for controlled and targeted drug release systems offering cancer therapy at its best Chugh et al.(2018). Modifying AgNPs will allow specific targeting of tumor cells; new therapeutic strategies may develop within this scope and transform methodologies applied to cancer treatment.

CONCLUSION

In conclusion, Silver nanoparticles offer a promising and polyhedral approach within the medical field to combat some of the most important health challenges antibiotic resistance and cancer treatment. But in order to take full advantage of their benefits, an important aspect that should be considered is their safety and environmental impact. Further research innovations in synthesis and application will surely advance the role of AgNPs in modern medicine. The use and technology of nanoparticles for medicine currently represent one of the fastest-growing areas going from design to application improvements for all kinds of therapy fields. This review article has drawn together an overview based on that described concerning the properties, applications, and related mechanisms for various types of nanoparticles while also offering some new insight into effective contributions. To fill current information voids and identify fresh opportunities for investigation that might assist in optimizing therapeutic potential when applied clinically, moving forward is necessary. silver nanoparticles constitute a multipronged approach to cancer treatment, the possible roles of which extend even beyond direct cytotoxicity toward enhancing drug delivery and efficacy. Incorporation of AgNPs into regimens for cancer treatment may hold promise in addressing some of the limitations of conventional therapies. Further and more intensive studies are, however, required to fill existing gaps in knowledge not only about their safety but also their therapeutic mechanisms that would lead to new and improved cancer treatment applications.

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