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Emerging trends in nanopharmacology: new therapeutic approaches to paediatric parasitology

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ABSTRACT

New and emerging trends, particularly in the employment of nanotechnology for the treatment of paediatric parasitic infections, are transforming the therapeutic modalities of parasitic diseases that largely affect children. This review outlines how nanopharmacological methods, especially liposomal and polymeric nanoparticles, boost drug delivery systems and transform treatment options for parasitic infections in children. Emerging nanopharmacological methods can be combined with recent discoveries with practical applications in the diagnosis, vaccine development, and fighting of drug-resistant organisms. We, herein, also briefly present the novel horizons of nanopharmacology and how the advancements in the field that must overcome existing limitations (such as the development of drug resistance and the low bioavailability of several therapeutic agents) by refining the effectiveness and the selection of therapeutic solutions. The combined application of nanotechnology and paediatric parasitology could be the ultimate approach to improving the quality of paediatric health, especially in developing countries. Finally, this review highlights current and future directions for paediatric parasitology, as it handles drug resistance and enhances therapeutic effectiveness while developing better vaccine technologies.

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1. Introduction

Parasitic infections are the leading aetiology of paediatric morbidity and remain a public medical problem in low-income countries. Diseases, such as malaria, schistosomiasis, and leishmaniasis, may result in severe morbidity and death among children. Conventional pharmacological interventions face problems such as poor solubility, drug resistance, and adverse effects[1]. Nanotechnology exploits the structure of nanoparticles in an attempt to enhance therapeutic efficacy[2]. This article reviews various aspects of nanotechnology as a dynamic field in contemporary science, and how its progress can affect the field of paediatric parasitology.

2. Understanding nanoparticles in the context of drug delivery

Nanoparticles are molecules that are less than or equal to 1 μm in size and greater than or equal to 1 nm. Their small size enables them to possess certain physicochemical characteristics that can be exploited for medical applications[3]. Many types of nanoparticles have been employed in the field of nanopharmacology, including: (i) liposomes (spherical vesicles that can encapsulate hydrophilic and hydrophobic drugs in order to enhance their delivery and/or decrease their toxicity)[2–4], (ii) polymeric nanoparticles (deriving from biocompatible polymers and designed to deliver drugs under certain conditions, such as changes in pH or temperature)[2,3], (iii) solid lipid nanoparticles (SLNs; although having features that resemble both liposomes and polymeric nanoparticles, SLNs simultaneously offer extended drug release with biocompatibility)[2,3], and (iv) dendrimers (branched macromolecules that can be synthesized with a high degree of controlled-drug delivery applications because of the clear structure of the branched micromolecules)[2,3].

Nanoparticles can improve drug delivery through several mechanisms: (i) targeted delivery (through functionalization with ligands that interact with specific parasitic receptors, the drug concentration at the site of parasitic infection can be increased, while the overall toxicity is reduced), (ii) controlled release (some nanoparticles have been developed to stimulate drug release over time, thereby maintaining circulatory therapeutic concentrations), and (iii) enhanced permeability (nanoparticles can increase the absorption of expensive drugs and reduce the impact of biological barriers because of their molecular structure)[3,5].

3. Applications of nanotechnology in paediatric parasitology

Another area where growth is observed almost as revolutionary is the drug delivery techniques introduced in the nanotechnology field when working with children with parasitic diseases. Liposomal formulations have been shown to be potential treatments for parasitic diseases. For instance, liposomal amphotericin B is used for the treatment of visceral leishmaniasis[3,4]. They increase the bioavailability of drugs and decrease nephrotoxicity when compared with classical preparations. Randomized controlled trials have confirmed that liposomal formulations are beneficial in such subjects[2,3].

Polymeric nanoparticles can be used to encapsulate and deliver antiparasitic drugs, such as antimalarial artemisinin. Through sustained release kinetics, systemic therapeutically-relevant concentrations are achieved and sustained for prolonged durations, thereby enhancing treatment compliance and long-term outcomes[2,3].

On the other hand, parasitic infections must be diagnosed at an early stage for the achievement of a better treatment. Traditional diagnostic approaches are insensitive and nonspecific, resulting in delayed treatment and a poor prognosis[1]. Nanotechnology has been proven to provide good results in the development of biosensors with improved sensitivity and speed compared to traditional biosensors, including: (i) gold nanoparticles (such nanoparticles can enhance diagnostic signalling assays because of their unique optical characteristics; they are used as conjugates in lateral flow assays for the rapid diagnosis of malaria and other parasitic infections) and (ii) quantum dots (semiconductor nanoparticles have peculiar fluorescence ability that can be employed in the imaging and detection processes; quantum dots labelled with parasitic antigen antibodies provide a highly sensitive detection technique)[2,5].

A major goal of disease control is vaccination, and vaccines have been developed for a multitude of viral

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and bacterial diseases. The development of effective vaccines to immunize against parasitic diseases has been difficult due to the parasites' complicated life cycles and their high rate of antigenic variation[6]. The use of nanoparticles in vaccines could provoke a very effective immune system reaction against parasitic diseases, particularly through: (i) their adjuvant properties (nanoparticles possess the property of an immune adjuvant when conjugated to antigens; this approach has been proposed for vaccines against malaria and schistosomiasis)[6] and (ii) targeted antigen delivery (using nanoparticles that have a preference for certain immune cells, such as dendritic cells, can improve antigen uptake and presentation, thereby improving the immune response)[6,7].

Drug-resistant parasites present a substantial challenge for treatment efficacy. Nanoparticles can offer novel solutions to this issue[1,2,7]. Ordered drug delivery using nanotechnologies can enhance drug efficacy because parasites are targeted using multiple modalities[2,7]. Antimalarial agents can be combined with secondary drugs in order to improve the chance of eradicating the parasites with a lower possibility of inducing drug resistance[8]. Finally, scientists can achieve targeted delivery, minimize off-target effects, and improve drug effectiveness by altering the nanomolecular surface to ligands that distinguish targeted parasitic receptors[7].

4. Perspectives of nanopharmacology for paediatric parasitology

Despite optimistic improvements, the nanotechnological applications for the treatment of paediatric parasitic diseases are still limited. Future studies should emphasize on the following: (i) optimizing formulations (adapting nanopharmacological formulations to certain parasites is vital for the optimization of therapeutic benefits with fewer adverse effects)[7], (ii) securing prolonged safety profiles (evaluating the long-term safety profiles of nanoparticle-based treatments is vital before their deployment in clinical settings)[8], and (iii) conducting clinical trials (nanotherapies, predominantly in the paediatric field, will need to be assessed for their efficacy and safety through the undertaking of additional clinical trials).

Integrating nanotechnology with future health strategies could substantially impact worldwide efforts to fight parasitic diseases in children. Where parasitic diseases are most predominant in poor populations, health outcomes can be improved by refining access to actual management through affordable nanopharmacological solutions. In fact, emergent economic nanoparticle-based medications could facilitate extensive adoption in low-resource areas[2,8]. Funding programs and infrastructure for research should be initiated in order to ensure the practical application of nanotechnology developments in the public welfare system[2,9].

In order to optimize the possible benefits of nanopharmacology in combating paediatric parasitic diseases, educational initiatives must be employed at several levels: (i) training healthcare professionals (strengthening training programs for nanopharmacology will ensure that healthcare providers have adequate knowledge in applying emerging enhanced technologies) and (ii) community awareness programs (educating communities about parasitic diseases and nanotechnology treatments for diseases will help families obtain proper early treatment)[1,2,9]. Moreover, the collaboration between researchers, industry partners, and government agencies will drive innovation and the fast-track development of satisfactory new nanotechnology solutions specifically designed for use in paediatrics[9].

Similar to any evolving biotechnology, ethical considerations should be addressed when implementing nanopharmacological methods in the treatment of paediatric patients. It is also fundamental to guarantee that parents or guardians are fully informed of the pros and cons of new therapies for their children's conditions. Finally, equity in the access of these medications should be ensured, while the generation and elimination of nanoparticles should also be evaluated for their environmental impacts, thereby ensuring sustainability in their use[10].

5. Conclusion

Nanopharmacology is a promising model for pharmacotherapy in children with parasitic infections. These applications mean that nanoparticles can improve the effectiveness of drug delivery systems, boost the accuracy of diagnostic tests, and create vaccines against parasitic diseases that affect children worldwide. Additional research and funding in this regard are desirable in order to allow us to understand the potential of nanotechnology to positively impact the health of deprived children worldwide. As we build concepts and directions for these technologies, we ensure a ready solution to a core set of problems related to parasitic infections in children.

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Conflicts of interest

None exist.

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