The Role of Nanotechnology in Improving the Parasite's Antitumor Effects

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Abstract

In recent decades, immunotherapy has been a promising cancer treatment approach. However, these methods' limited results and side effects have revealed the need to improve and strengthen them. This article aims to review this field's progress, challenges, and future perspectives. It will analyze the critical role of these approaches in developing more effective and safer treatments for cancer patients. Cancer immunotherapy is an innovative method to enhance immunotherapy's effects by using parasites as immune system stimulants. Different parasites such as *Echinococcus granulosus* (*E. granulosus*), *Trichinella spiralis* (*T. spiralis*), *Trypanosoma cruzi* (*T. cruzi*), and *Toxoplasma gondii* (*T. gondii*) have molecules and mechanisms that can modulate and strengthen the body's immune responses. *E. granulosus*, which causes Cystic echinococcosis (CE), can stimulate the immune system and be an adjuvant in cancer immunotherapy. *T. spiralis* is another parasite that has the potential to be used in immunotherapy treatments due to its intense stimulation of the host's immune system. The *T. cruzi*, which causes African sleeping sickness, has proteins and molecules that can help boost immune responses. *T. gondii*, the protozoan parasite that causes toxoplasmosis, has also attracted the attention of researchers due to its ability to stimulate the immune system. In this review article, the role of these parasites in enhancing cancer immunotherapy is investigated, as well as their molecular and cellular mechanisms. In addition, the role of nanocoatings in improving the efficiency and safety of these methods will be examined. In conclusion, nanocoatings can act as intelligent carriers for precise and effective delivery of immunostimulating molecules and minimize side effects. Combining parasites and nanocoatings can be used as a new multidimensional approach to cancer treatment and significantly improve treatment results.

٤٨ **Keywords:** Parasites; Cancer immunotherapy; *Echinococcus granulosus*; *Trichinella spiralis*;
٤٩ Nanocoatings

1. Context

Cancer treatment is one of the significant medical challenges of today (1). Despite significant advances in the diagnosis and treatment of cancer, many patients still suffer from insufficient treatment response and severe side effects (2, 3). Immunotherapy has been proposed as an innovative cancer treatment method that fights cancer cells by stimulating the body's immune system. Cancer immunotherapy, which has been widely used in the last few years, has the primary goal of stimulating the body's immune system in such a way that it can identify and destroy cancer cells. However, limited efficacy and variable responses in different patients have revealed the need to improve and strengthen these methods (4, 5).

For all its advantages, immunotherapy still faces several challenges (6). Many patients do not respond well to this procedure; in some cases, overly immune responses can lead to serious side effects (7). Therefore, it is necessary to find ways to increase the efficiency and reduce the side effects of this method. In this regard, using parasites as immune system stimulants is one of the new and promising approaches. Due to their complex and long-term interactions with the host's immune system, parasites can modulate and enhance immune responses.

In recent years, there has been some shreds of evidence that parasites can effectively enhance the body's immune responses. Parasites such as *E. granulosus*, *T. spiralis*, *T. cruzi*, and *T. gondii* have attracted the attention of researchers due to their unique abilities to interact with the immune system (8). These parasites can help increase the efficiency of immunotherapy in cancer treatment by stimulating and modulating immune responses. These parasites' biological characteristics and specific mechanisms have made them potential tools to enhance immunotherapy (Table 1).

٧١ Table 1. A detailed table describes the specific parasites' anticancer mechanisms and the cell

٧٢ lines used in research.

Parasite	Cell Lines	Anticancer Mechanism	Key Findings
Echinococcus granulosus (E. granulosus)	HepG2 (Liver cancer), HeLa (Cervical cancer)	- Induces apoptosis through mitochondrial pathways.	Protoscolex extracts show cytotoxic effects and reduced cancer cell proliferation.
		- Alters immune response, increasing pro-apoptotic cytokines (e.g., IL-2, IFN-γ).	Encourages immune-mediated destruction of cancer cells.
Trichinella spiralis (T. spiralis)	A549 (Lung cancer), HCT116 (Colorectal cancer)	- Secretes excretory-secretory (ES) products that inhibit tumor growth.	ES products downregulate angiogenic factors like VEGF.
		- Modulates the immune system, promoting an anti-tumor Th1 response.	Suppresses tumor progression by enhancing immune surveillance.

Trypanosoma cruzi (T. cruzi)	MCF-7 (Breast cancer), U87 (Glioblastoma)	- Releases cruzipain, which triggers apoptosis and cell cycle arrest in cancer cells.	Cruzipain induces oxidative stress, leading to DNA damage in cancer cells.
		- Alters tumor microenvironment, reducing cancer cell survival.	*T. cruzi*-infected macrophages show enhanced tumoricidal activity.
Toxoplasma gondii (T. gondii)	SKOV3 (Ovarian cancer), CT26 (Colon cancer)	- Utilizes dense granule proteins (GRAs) to induce apoptosis and inhibit proliferation.	GRAs stimulate immune cells to secrete IFN-γ and TNF-α, promoting anti-cancer effects.
		- Enhances immune system activity, leading to tumor regression.	*T. gondii* infection leads to increased infiltration of cytotoxic T cells in tumor sites.

2. Data Acquisition

E. granulosus, the causative agent of hydatidosis, has molecules and proteins that stimulate the body's immune responses. These features have caused CE to be proposed as a potential adjuvant in cancer immunotherapy. Research has shown that different components of *E. granulosus* can help strengthen therapeutic effects and reduce side effects (9, 10). The surface proteins and components of *E. granulosus* can stimulate immune responses, which can be used as a booster in immunotherapy methods (11).

T. spiralis, another parasite known for enormously stimulating the host's immune system, also has excellent potential for use in immunotherapy treatments. *T. spiralis* can modulate and strengthen the body's immune responses by producing specific molecules, improving treatment results. *T. spiralis*'s ability to generate a strong and sustained immune response has made it an attractive option for researchers in the field of cancer immunotherapy (12, 13). Studies have shown that *T. spiralis*-derived molecules can effectively help stimulate the immune system (14, 15).

T. cruzi, the causative agent of African sleeping sickness, and *T. gondii*, the causative agent of toxoplasmosis, have also received attention for their unique abilities to stimulate the immune system (16). Using different molecular and cellular mechanisms, these parasites can strengthen the body's immune responses and help increase the efficiency of immunotherapy. The surface proteins and antigens of these parasites are designed in such a way that they can improve the body's immune responses. These parasites and their derived molecules can be studied and used as a complementary method in cancer immunotherapy (17).

In addition, nanocoatings, one of the new developments in medicine, can play an essential role in improving the efficiency and safety of these methods (18). Nanocoatings can minimize side effects

and improve therapeutic outcomes by providing precise and effective delivery of immunostimulating molecules (19, 20). This new technology can act as an intelligent carrier to deliver effective molecules to desired locations in the body. Combining parasites and nanocoatings can be a multidimensional and practical approach to cancer treatment and significantly improve treatment results. Hence, the current study aims to review this field's advances, challenges, and future perspectives. Using parasites and nanocoatings as a new and multidimensional strategy can open new horizons in cancer treatment and lead to more advanced treatment methods.

3. Results

3.1. *Echinococcus granulosus*

E. granulosus is a worm parasite that causes hydatidosis in humans and animals. *E. granulosus* is usually transmitted to humans through the eggs in the feces of dogs and creates hydatid cysts in various body organs, including the liver and lungs. Recent studies have shown that *E. granulosus* can be influential in modulating and strengthening the body's immune system and can be proposed as a new tool in cancer treatment (21). One of the main mechanisms of the anticancer effects of *E. granulosus* is the production of immunomodulatory molecules that can regulate the body's immune responses (10). These molecules include proteins and peptides produced by the parasite and can alter the activity of immune cells such as macrophages, dendritic cells, and lymphocytes. For example, one of these molecules, *E. granulosus* antigen B protein (EgAgB), can stimulate the production of inflammatory cytokines such as interleukin-12 (IL-12) and interferon-gamma (IFN-γ), which can enhance anti-cancer immune responses (9, 22). *E. granulosus* can help destroy cancer cells by stimulating cellular immune responses, especially killer T cells (CTLs). Studies have

shown that the parasite's antigens can increase the proliferation and activity of T cells. For example, in one study, the injection of *E. granulosus* antigens into mice with melanoma caused a significant increase in the number and activity of killer T cells, which led to a decrease in the size of the tumors (23).

Another mechanism of the anticancer effects of *E. granulosus* is the inhibition of signaling pathways related to the growth and survival of cancer cells (24). For example, proteins extracted from hydatid cysts can inhibit PI3K/Akt and MAPK signaling pathways, which are active in many types of cancer and play an essential role in cancer cell survival. Inhibition of these pathways can reduce the proliferation of cancer cells and increase their sensitivity to apoptosis. In addition to enhancing adaptive immune responses, *E. granulosus* can also enhance innate immune responses (25). For example, *E. granulosus* can increase the production of neutrophils and macrophages and strengthen their activity. Neutrophils and macrophages play an essential role in identifying and destroying cancer cells, and enhancing their activity can help reduce the growth and spread of tumors (26). For example, in one study, injecting *E. granulosus* antigens into mice with colorectal cancer led to increased macrophage activity and a significant reduction in tumor size.

3.2. *Trichinella spiralis*

T. spiralis is a nematode parasite that causes trichinosis in humans and animals. *T. spiralis* enters the body by consuming contaminated raw or undercooked meat, multiplies in the small intestine, and its larvae migrate to the skeletal muscles through the bloodstream. In recent years, several studies have investigated the role of *T. spiralis* in stimulating and modulating the immune system, which can be used as a new approach to cancer treatment (12, 27). *T. spiralis* can stimulate anti-

tumor immune responses. One of the key molecules of *T. spiralis* is excretory-secretory (ES) products, which are secreted by *T. spiralis* larvae. These molecules can increase dendritic cells' activity and improve the antigen presentation to T cells. The activated T cells can then directly target and destroy cancer cells (28). For example, in one study, injecting ES products into mice with lung cancer led to reduced tumor growth and increased survival. *T. spiralis* can balance inflammatory and anti-inflammatory immune responses by modulating immune pathways (29). *T. spiralis* can increase the production of inflammatory cytokines such as IL-12 and IFN-γ and simultaneously decrease the production of anti-inflammatory cytokines such as interleukin-10 (IL-10) (30). This fine-tuning of immune pathways can help reduce tumor growth and inhibit metastasis. For example, a study showed that *T. spiralis* can inhibit NF-κB signaling pathways and thereby reduce the proliferation of cancer cells.

T. spiralis can also enhance innate immune responses. Macrophages, neutrophils, and NK cells are innate immune cells that identify and destroy cancer cells. *T. spiralis* can increase the production and activity of these cells (31). For example, in one study, injecting *T. spiralis* larvae into mice with colorectal cancer led to increased macrophage activity and a significant reduction in tumor size. *T. spiralis* can change the tumor microenvironment into an immunogenic environment (15). By stimulating the production of different cytokines and chemokines, *T. spiralis* can increase the penetration of immune cells into the tumor. This process can lead to improved anti-tumor immune responses and reduced tumor growth. For example, a study showed that *T. spiralis* can inhibit the growth of melanoma by increasing the penetration of T cells and macrophages into the tumor.

3.3. *Trypanosome cruzi*

T. cruzi is a protozoan parasite that causes Chagas disease in humans. *T. cruzi* has significant potential to stimulate and modulate the body's immune system, which could be helpful in cancer treatment (32). One of the main mechanisms of the anti-cancer effects of *T. cruzi* is the stimulation of anti-tumor immune responses. *Trypanosome cruzi* can increase the activity of immune cells, such as dendritic and T cells, by producing and secreting immunomodulatory molecules (33). For example, *T. cruzi* surface proteins, such as surface glycoproteins (TSGP), can enhance the activity of dendritic cells and improve the presentation of antigens to T cells. This process can increase the proliferation and activity of killer T cells that directly target and destroy cancer cells (34).

T. cruzi can apply its anticancer effects by inhibiting the signaling pathways related to the growth and survival of cancer cells (34). For example, some proteins extracted from *T. cruzi* can inhibit PI3K/Akt and MAPK signaling pathways, which are active in many types of cancer and play an essential role in the survival of cancer cells. Inhibition of these pathways can reduce the proliferation of cancer cells and increase their sensitivity to apoptosis (35). *T. cruzi* can balance inflammatory and anti-inflammatory immune responses by modulating the body's immune system. *T. cruzi* can increase the production of inflammatory cytokines such as IL-12 and IFN-γ and simultaneously decrease the production of anti-inflammatory cytokines such as IL-10 (36). This fine-tuning of immune pathways can help reduce tumor growth and inhibit metastasis. For example, a study showed that *T. cruzi* can inhibit NF-κB signaling pathways and thereby reduce the proliferation of cancer cells.

In addition to enhancing adaptive immune responses, *T. cruzi* can also enhance innate immune responses. Macrophages, neutrophils, and NK cells are innate immune cells that identify and destroy cancer cells (37). *T. cruzi* can increase the production and activity of these cells. For example, in one study, injection of *T. cruzi* into mice with lung cancer led to increased activity of

macrophages and neutrophils and a significant reduction in tumor size. *T. cruzi* can provide conditions for more effective immune responses by altering the tumor microenvironment. By stimulating the production of chemokines and adhesion molecules, *T. cruzi* can increase the penetration of immune cells into the tumor (38).

3.4. *Toxoplasma gondii*

T. gondii is a protozoan parasite that causes toxoplasmosis in humans and animals. It enters the body through food or water contaminated with oocysts or mother-to-fetus transmission. *T. gondii* can cause cysts in different body tissues, such as the brain, eyes, and skeletal muscles. In recent years, several studies have investigated the modulating effects of *T. gondii* on the body's immune system and its possible applications in cancer treatment (39). *T. gondii* can exert its anticancer effects by stimulating antitumor immune responses. *T. gondii* can increase dendritic and T cells' activity by producing and secreting immunomodulatory molecules such as secretory proteins (SAGs and GRAs). For example, *T. gondii* surface antigens (SAG1 and SAG3) can activate dendritic cells and present antigens to T cells, leading to increased IFN-γ production and stimulation of antitumor immune responses. In one study, injection of *T. gondii* antigens into mice with ovarian cancer resulted in a significant reduction in tumor size and increased survival of the mice.

T. gondii can exert its anticancer effects by inhibiting signaling pathways related to the growth and survival of cancer cells. Some proteins of *T. gondii* can inhibit PI3K/Akt and MAPK signaling pathways, which are active in many types of cancer and play an essential role in the survival of cancer cells (40). Inhibition of these pathways can reduce the proliferation of cancer cells and

increase their sensitivity to apoptosis. For example, in one study, injecting proteins extracted from *T. gondii* into mice with liver cancer inhibited the PI3K/Akt pathway and reduced tumor growth.

T. gondii can balance inflammatory and anti-inflammatory immune responses by modulating the body's immune system (41). A study showed that *T. gondii* can inhibit NF-κB signaling pathways and thereby reduce the proliferation of cancer cells. In addition to enhancing adaptive immune responses, *T. gondii* can also enhance innate immune responses (42). *T. gondii* can increase the production and activity of these cells. For example, in one study, injection of *T. gondii* into mice with lung cancer led to increased activity of macrophages and neutrophils and a significant reduction in tumor size.

T. gondii can alter the tumor microenvironment to provide conditions for more effective immune responses (43). By stimulating the production of chemokines and adhesion molecules, *T. gondii* can increase the penetration of immune cells into the tumor. This process can lead to improved anti-tumor immune responses and reduced tumor growth. For example, in one study, injection of *T. gondii* into mice with melanoma led to increased T cells and macrophage infiltration into the tumor and inhibition of tumor growth (44).

3.5. Nanotechnology and nanocoating

As a new field in science, Nanotechnology has brought about huge changes in medicine and has vulnerable applications in diagnosis, crises, and diseases. This technology, using nanoparticles and materials in nanometers, allows the design of targeted systems for drug delivery, gene therapy, and tissue repair. For example, lipid and polymer nanoparticles as drug carriers help increase the bioavailability of drugs, reduce side effects, and increase their effectiveness. In disease diagnosis,

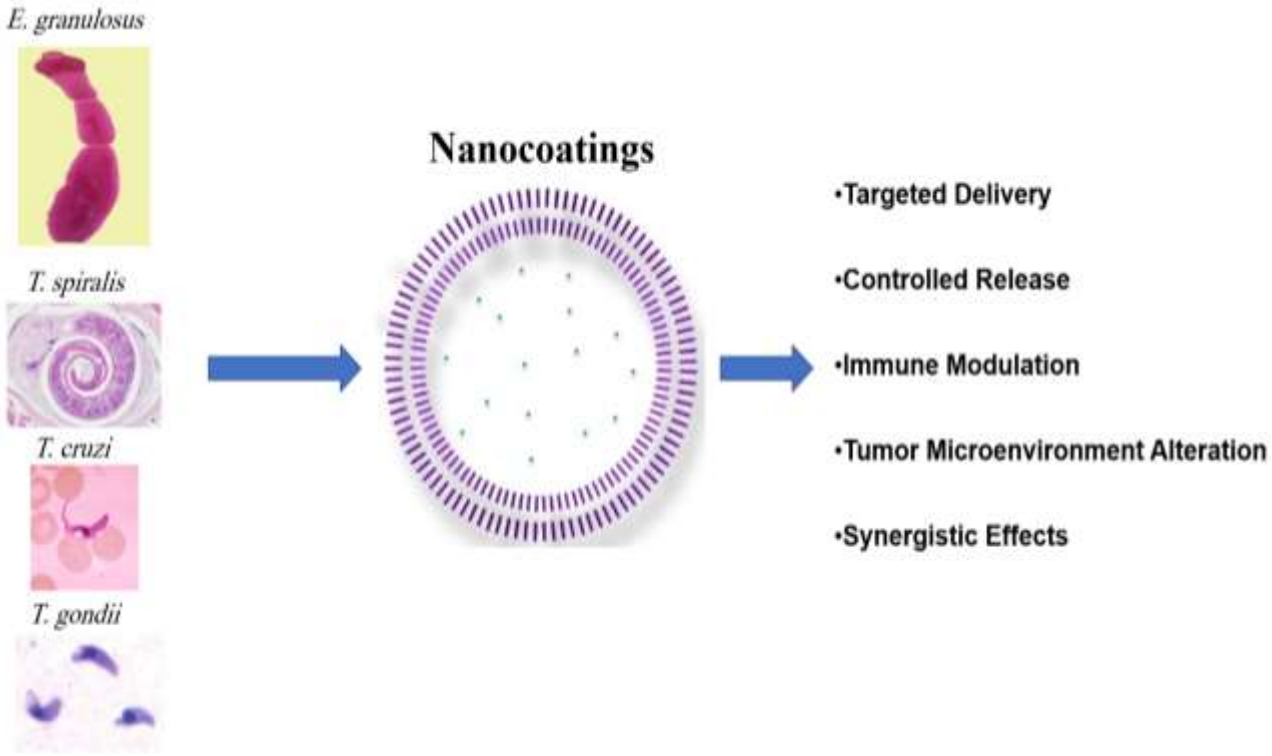
nanobiosensors and gold and silver nanoparticles are naturally used for rapid and sensitive diagnosis of diseases such as cancer, infectious diseases, and metabolic disorders. Additionally, nanoparticle systems such as magnetic nanoparticles are used in the therapy field to guide drugs to the precise location of tumors and treat cancer. In addition, nanotechnology has played a key role in developing new vaccines, including RNA vaccines with lipid nanocarriers, a prime example of which is the production of COVID-19 vaccines. These advances demonstrate the enormous potential of nanotechnology in improving the quality of life and developing personalized therapies that are shaping the horizons of modern medicine.

Nanocoatings, especially lipid nanocoatings, play a vital role in the modern world of medicine and pharmaceuticals. Due to their unique properties, these coatings with nano dimensions (usually less than 100 nm) and their particular structure have become powerful tools for drug delivery and enhancing biological functions (45, 46). Lipid nanocoatings, in particular, comprise lipid layers similar to cell membranes' structure. For this reason, they can penetrate and interact with body cells and tissues. These properties allow them to effectively deliver drugs to the precise points of interest and enhance their therapeutic and preventive effects. In drug delivery, lipid nanocoatings can quickly enter cells and target the target tissues due to their structural similarity with cell membranes (47). This capability is critical in targeted drug delivery, where there is a need for high precision in delivering the drug to specific parts of the body. Using lipid nanocoatings, drugs can be directly and accurately delivered to specific tissues such as cancer tumors. This reduces the amount of drugs needed and adverse side effects in other parts of the body, which helps improve the patient's quality of life and increases the treatment's effectiveness.

In addition to targeted drug delivery, lipid nanocoatings are particularly effective in enhancing anti-parasitic antigens (48). These nanocoatings can effectively transfer specific antigens to the

target tissues to stimulate the body's immune system and fight against parasites. This technology can be particularly effective in diseases caused by parasites that require strong immune system stimulation. By covering antigens and presenting them to specific body areas, lipid nanocoatings help strengthen the immune response and increase the body's ability to fight against parasites. In cancer treatments, lipid nanocoatings play a crucial role (49). These nanocoatings can deliver anti-cancer drugs to cancer cells in a targeted manner and thus reduce the dose of drugs used. With this technology, drugs are precisely transferred to the desired sites, reducing side effects in healthy tissues and increasing the treatment's effect on cancerous tumors. In addition, lipid nanocoatings can help deliver drugs to complex and inaccessible environments such as high-grade tumors and improve cancer treatments.

Lipid nanocoatings also have a high potential for improving therapeutic capabilities and disease prevention. By providing drugs in a controlled and targeted manner, these coatings can be used as practical tools to reduce drug side effects and increase the impact of various treatments. This technology is constantly evolving, and it is expected that shortly, with further developments, it will offer more capabilities in treating diseases and improving people's health. In general, lipid nanocoatings, with their unique properties, are considered an advanced technology in pharmaceuticals and medicine. Due to their high capabilities in improving drug delivery and strengthening biological functions, these coatings can help transform treatment methods and improve patients' quality of life. Due to the continuous progress in this field, it is hoped that lipid nanocoatings will play broader roles in improving treatments and combating diseases shortly and will be recognized as crucial tools in various fields of medicine and pharmaceuticals (Figure 1) (Table 2).



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٢٧٦ Figure 1. Nanocoatings enhance anticancer efficacy through targeted delivery, controlled release,
٢٧٧ immune modulation, tumor microenvironment alteration, and synergistic effects with
٢٧٨ antiparasitic properties.

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٢٨٠ Table 2. This table highlights the diverse applications of nanotechnology in medicine and their
٢٨١ potential to revolutionize healthcare.

Field of Application	Nanotechnology Applications	Advantages	Examples/Key Innovations

Drug Delivery	- Nanocarriers (liposomes, dendrimers, polymeric nanoparticles).	- Targeted delivery to specific tissues, reducing off-target effects.	- Liposomal doxorubicin for cancer therapy (Doxil).
	- Stimuli-responsive systems (pH, temperature, or light-sensitive nanoparticles).	- Controlled and sustained drug release, improving therapeutic efficacy.	- Temperature-sensitive nanoparticles for localized drug delivery in tumors.
	- Hydrophobic drug encapsulation.	- Enhanced solubility of poorly water-soluble drugs.	- Encapsulation of paclitaxel in polymeric nanoparticles.
Cancer Therapy	- Gold nanoparticles for photothermal therapy.	- Selective tumor ablation with minimal damage to surrounding tissues.	- Gold nanoparticle-mediated tumor ablation via near-infrared radiation.
	- RNA interference (RNAi) nanocarriers.	- Specific gene silencing for oncogene inhibition.	- siRNA-loaded lipid nanoparticles for KRAS-mutant cancers.

	- Nanovaccines targeting tumor antigens.	- Enhanced immune response against cancer cells.	- Nanoparticles loaded with tumor-associated antigens for immunotherapy.
Diagnostics	- Quantum dots for imaging and detection.	- High sensitivity and specificity for early disease detection.	- Quantum dot-based multiplexed detection of cancer biomarkers.
	- Nanobiosensors.	- Real-time, on-site diagnostics for infectious diseases and cancers.	- Glucose monitoring using nanosensors in diabetic patients.
Regenerative Medicine	- Nanoscaffolds for tissue engineering.	- Mimics extracellular matrix, enhancing cell adhesion and proliferation.	- Electrospun nanofibers for skin and cartilage regeneration.
	- Stem cell delivery using nanomaterials.	- Improved survival and localization of stem cells in damaged tissues.	- Nanoparticle-coated stem cells for cardiac repair post-myocardial infarction.

Infectious Diseases	- Silver nanoparticles as antimicrobial agents.	- Broad-spectrum activity against bacteria, viruses, and fungi.	- Silver-coated wound dressings to prevent infections.
	- Liposomal carriers for antiviral drugs.	- Enhanced delivery of antiviral drugs to infected cells.	- Liposomal amphotericin B for fungal infections.
Cardiology	- Nanoparticles for targeted drug delivery to atherosclerotic plaques.	- Reduced systemic side effects of cardiovascular drugs.	- Lipid-based nanoparticles for siRNA delivery in hyperlipidemia.
	- Magnetic nanoparticles for imaging and therapy.	- Real-time monitoring of heart disease progression.	- Iron oxide nanoparticles for MRI imaging of atherosclerotic plaques.
Neurology	- Nanoparticles crossing the blood-brain barrier (BBB).	- Delivery of drugs for neurodegenerative diseases like Alzheimer's and Parkinson's.	- Polymeric nanoparticles for targeted delivery of dopamine to the brain.

	- Nanotechnology in neuroprotection.	- Minimizing oxidative stress and neural damage.	- Cerium oxide nanoparticles as free radical scavengers in stroke treatment.
Vaccinology	- Nanovaccines for infectious diseases.	- Enhanced immunogenicity with lower doses.	- Lipid nanoparticle mRNA vaccines for COVID-19 (e.g., Pfizer-BioNTech, Moderna).
	- Adjuvants in nanovaccine formulations.	- Boosted immune responses to weak antigens.	- Aluminum hydroxide nanoparticles as vaccine adjuvants.
Ophthalmology	- Nanodrops for corneal drug delivery.	- Improved penetration and bioavailability in ocular tissues.	- Lipid nanoparticles for glaucoma treatment.
	- Nanoscaffolds for corneal repair.	- Accelerated wound healing and reduced scarring.	- Silk fibroin-based nanoscaffolds for corneal regeneration.
	- Nanocomposites for bone repair.	- Improved mechanical properties and bioactivity.	- Hydroxyapatite nanoparticles in bone cement.

Orthopedics	- Antimicrobial nanocoatings for implants.	- Reduced implant-associated infections.	- Silver nanoparticle-coated orthopedic implants.
Dermatology	- Nanoparticles in sunscreen.	- Better UV protection with reduced skin irritation.	- Titanium dioxide and zinc oxide nanoparticles in sunscreens.
	- Nanocarriers for transdermal drug delivery.	- Enhanced penetration of drugs through the skin barrier.	- Liposomes and micelles for transdermal delivery of corticosteroids.
Endocrinology	- Nanotechnology in diabetes management.	- Continuous glucose monitoring and insulin delivery.	- Glucose-sensitive nanoparticles for controlled insulin release.
Environmental Medicine	- Detoxification using nanomaterials.	- Removal of heavy metals and toxins from the body.	- Functionalized carbon nanotubes for lead and mercury chelation.

3.6. Future challenges

Parasite antigens with anticancer properties have attracted much attention as a new and promising field in anticancer treatments. These antigens, usually derived from specific proteins or molecules in parasites, have been explored in recent research as a new strategy in cancer treatment due to their ability to stimulate a robust immune response and direct immune cells to cancer tumors. These antigens can help activate the immune system and increase the body's sensitivity to cancer tumors. Still, this process requires a suitable substrate for effectively transferring these antigens to the target sites. One of the main challenges in using parasite antigens as anti-cancer treatments is the practical and targeted delivery to specific body areas. Nanocoatings can provide an effective solution to this problem. By using lipid nanocoatings, these antigens can be precisely targeted to tumoral cells, which helps to increase the therapeutic effect and reduce side effects. Nanocoatings, with their properties such as tissue penetration and controlled release of active substances, can help improve the delivery of parasite antigens and enhance their anticancer properties.

However, using nanocoatings to enhance the effects of parasite antigens is associated with several challenges. One of these challenges is to ensure the nanocoatings' stability during the transfer to the target site. Nanocoatings should be designed to resist physiological conditions such as pH and enzymes to effectively deliver antigens to their destination (50). Furthermore, optimizing the size and surface of nanocoatings to increase their absorption and reduce their excretion from the body is another critical issue that should be considered. Another challenge is managing possible immune reactions to nanocoatings and transferred antigens. Nanocoatings or antigens may induce unwanted immune responses that can negatively affect the therapeutic effect. It is of great importance to design nanocoatings in a way that minimizes side effects and directs immune

responses to impact treatment positively. In addition, the cost of production and scalability of nanocoatings can also be a severe obstacle to their widespread use. Finally, more research is needed to understand the mechanisms of action of parasite antigens and optimize nanocoating technologies. This research can lead to the design of new methods for more effective and safer transfer of antigens and improve the effectiveness of anti-cancer treatments. With more scientific and technological advances, it is hoped that nanocoatings and parasite antigens can lead to more successful treatments based on new technologies in dealing with cancer (Table 3).

Table 3. This table provides a structured overview of the field, which can be expanded further based on specific research findings.

Aspect	**Challenges**	**Future Prospects**
Drug Delivery Efficiency	Ensuring targeted delivery to cancerous and parasitic cells without affecting healthy tissues.	Development of smart nanocoatings with enhanced precision targeting capabilities.
Biocompatibility	Potential toxicity and adverse immune responses due to nanocoatings.	Advancements in biocompatible and biodegradable nanomaterials to minimize side effects.
Stability	Maintaining stability of nanocoatings under physiological conditions.	Engineering robust nanocoatings resistant to degradation in complex biological environments.

Cost and Scalability	High production costs and challenges in large-scale manufacturing of nanocoated drugs.	Development of cost-effective and scalable synthesis methods for industrial applications.
Regulatory Approvals	Stringent regulatory requirements for clinical trials and approval processes.	Establishing standardized protocols and guidelines to streamline regulatory approvals for nanomedicines.
Multifunctionality	Achieving simultaneous antiparasitic, anticancer, and therapeutic effects.	Designing multifunctional nanocoatings with combined diagnostic and therapeutic properties (theranostics).
Long-Term Effects	Lack of comprehensive studies on the long-term effects of nanocoating-based therapies.	Conducting longitudinal studies to assess long-term safety and efficacy of nanocoated drug systems.
Interaction with Microbiome	Possible disruption of the natural microbiome during treatment.	Designing coatings that selectively target pathogens while preserving beneficial microbiota.
Public Acceptance	Limited awareness and skepticism about the use of nanotechnology in medicine.	Educational campaigns and transparent communication to build

public trust in nanotechnology-based therapies.

Conclusion

Parasite antigens with anticancer properties have attracted much attention as a new approach to cancer treatment. These antigens can help activate a robust immune response against cancer tumors, but the main challenge in their practical use is precise and targeted delivery to the desired areas. Lipid nanocoatings can play a vital role in this field due to their unique properties, such as tissue penetration and controlled drug release. Using nanocoatings, it is possible to deliver targeted parasite antigens to tumoral cells, improving the effectiveness of anticancer treatments and reducing side effects. However, there are still challenges, including the stability of nanocoatings during the transduction pathway, management of immune reactions, and production costs. Research and scientific advances in this field can improve the design of nanocoatings and increase the efficiency of treatments based on parasite antigens.

Declarations and statements

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Author contribution

Conceptualization: [A.O], …; Methodology: [S.A.A., S.E., N.M.], …; Formal analysis and investigation: [M.F., N.H.S., A.O.], …; Writing - original draft preparation: A.D.D., S.G.S.]; Writing - review and editing: [All Authors], …; Funding acquisition: [Self-funding], …; Supervision: [A.O.]. All authors checked and approved the final version of the manuscript for publication in the present journal.

Ethical approval

On behalf of all co-authors, I hereby confirm that I have reviewed and complied with the relevant Instructions to Authors, the Ethics in Publishing policy, and Conflicts of Interest disclosure.

Conflict of interests

The authors declare no conflict of interest.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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