Innovative Approaches: Nanotechnology and Nanomedicine in the Fight against Hydatid Disease

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Abstract

Hydatidiosis is a zoonotic helminthic parasitic disease that is caused by *Echinococcus granulosus* that affects different hosts, and it is life-threatening. It is disturbed throughout the world, mainly in rural regions. For decades, millions of individuals have been aware that hydatid cysts are a prevalent medical condition. Individuals who have this illness may not exhibit any symptoms for years and only show up when their hydatid cysts, which are liver cysts, burst. The potential for nanotechnology to improve chemotherapy against hydatid cysts could pave the way for a revolution in medical care. This book chapter outlines how nanotechnology affects chemotherapeutics against hydatid disease. Delivering therapeutic drugs more precisely and effectively, targeting hydatid cysts more effectively, and reducing interaction with surrounding tissue are all made possible by nanotechnology. Nanotherapeutics do, however, present issues with resistance, toxicity, and biodistribution. In conclusion, there are a lot of challenges associated with using nanotechnology for treating hydatid cysts, despite the possibility of success. Additionally, nanobiosensors are used in diagnostic methods to aid in earlier and more precise patient diagnosis.

Keywords: Hydatidosis, Echinococcosis, Nanotechnology, Nanomedicine, Treatment

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Introduction

Hydatid disease, or uniocular cystic echinococcosis disease, is a zoonotic helminthic disease caused by the metacestod stage (hydatid cyst) of *Echinococcus granulosus*, presents significant health challenges globally, particularly in endemic regions (Moro & Schantz, 2009), and is mostly responsible for the increasing prevalence of echinococcosis worldwide (Budke *et al.,* 2006). The classical treatment of hydatid cysts till now depends on the surgical removal of the cyst and the use of drugs such as albendazole, but the use of drugs has side effects and drug resistance (Lupia et al., 2021, Karshima et al., 2022). *Echinococcus granulosus* forms cysts with a vibrable size, ranching from a pinhead to football size, and depressing the body organs and tissues (Alvi & Alsayeqh, 2022). If left without treatment, it will lead to fatal problems in humans and animals (Casulli et al., 2022). This parasite has a complex indirect life cycle and includes the carnivores as the final host and the herbivores, including humans, as the intermediate host. The intermediate hosts are infected by the ingestion of eggs of this parasite that pass with feces of the carnivores such as dogs and foxes (Zhang *et al.,* 2003; Zhang *et al.,* 2012). Several broad-spectrum antibacterial activities have been used for the treatment of this parasite as an antiparasitic agent, including azithromycin, azithromycin with paromomycin, rifaximin, nitazoxanide, and albendazole (Rossignol et al., 2006, Checkley et al., 2015). It works well for minor infections but is ineffective against moderate and severe illnesses (Diptyanusa & Sari, 2021).

The classical anthelmintic treatment of echinococcosis is albendazole and mebendazole, which inhibit the growth and proliferation of hydatid cysts (Adetunji et al., 2021, Chai et al., 2021). The using of these two anthelmintics has several side effects such as gastritis, and enteritis (Wang et al., 2020, Erfani et al., 2023). The treatment of echinococcosis is extended for months and up to years, therefore the prolonged using of these anthelmintics, resulted in the emergence of resistance (Taghipour et al., 2021, Alvi et al., 2023). Many problems still exist even if conventional chemotherapy is an effective treatment for hydatidosis (Wen et al., 2019). Working with large cysts or those located in complex anatomical areas may require altering the procedure (Kern et al., 2017). Many medications struggle to reach the parasite cores because of the challenges of breaking through cyst walls. Taking the patients' existing medical problems into account as well as any factors that might.

Early detection of hydatid cysts is essential for efficient treatment (Habibi et al., 2023*).* Unfortunately, because of its deceptive character and current diagnostic limitations, it is still challenging to detect this illness swiftly and reliably. However, because hydatid cysts can frequently be mistaken for other cystic lesions, imaging methods like ultrasound are helpful for offering first insights but are sometimes misconstrued (Dietrich et al., 2020*).* Magnetic resonance imaging and computerized tomography scans can provide high-resolution imaging, but they are costly and ineffective at differentiating between different types of cysts (Caraiani et al., 2020; Calame et al., 2022).

There are serological methods for screening for particular antibodies against *E. granulosus* antigens, such as Western blotting and ELISA, but these are also limited (Meftahi et al., 2021, Alvi et al., 2023). A Western blot continues to be more accurate than ELISA. Nevertheless, the probability of a false positive gets higher due to requiring specific resources and experience. It may be more challenging to figure out hydatid cysts because of their similarity to other cystic tumors (Alshoabi et al., 2023). Additionally, the current screening method typically finds cysts after they have significantly expanded, delaying early management that could improve results (Chouhan et al., 2019). In many cases, a definite diagnosis requires aspiration and biopsy (Khalili et al., 2023). However, there are risks associated with these treatments, including the potential for rupture and the development of cysts. When it comes to inert cysts or cysts that have calcified over time, serological testing is frequently ineffective (Paramita & Wibawa, 2023). The absence of advanced imaging and diagnostic technology in low-tech settings makes cancer identification more challenging (Borhani et al., 2021). More studies on hydatid cysts are needed, as are more precise and easily available diagnostic techniques.

Recent decades have seen the fusion of technological advancements and research innovations to give rise to a new field of study called nanotechnology, where system components are measured in billionths of meters and engineered and designed at the nanoscale, requiring extremely precise measurements (Sadr et al., 2023). This field is able to cross traditional boundaries, giving scientists basic control over matter (Sahu et al., 2021). The development of nanotechnology has great promise for the next several decades to transform medicine by providing a plethora of new opportunities that may fundamentally alter therapeutic approaches (Prasad et al., 2021, Sindhwani & Chan, 2021).

1.2. Nanoparticles

Dealing with materials that are nanometers in size (ranged between 1-100 nanometers) (Cho et al., 2013, Hasan, 2015, Mishra, 2016), for medical applications, nanomedicine is regarded as a relatively emerging area of science and technology. Drug delivery, imaging, diagnosis, medical devices, vaccinations, and antimicrobial therapy are only a few of the medicinal and diagnostic uses of nanomedicine that are currently available in contemporary medicine (Machado et al., 2015, Zhu et al., 2014). In light of the use of nanomedicine to treat microbial diseases, numerous studies have documented the antimicrobial properties of both organic and inorganic nanoparticles, including chitosan, synthetic cationic polymers, cationic peptides, and metal and metal oxide (*Sengul & Asmatulu, 2020)*.

Inorganic nanoparticles are metal-based and metal oxide-based nanoparticles are two more subcategories for them. The preparation of metal-based nanoparticles involves either constructive or destructive methods of turning the metals into nanoparticles. It is possible to produce nanoparticles from any kind of metal (Salavati-Niasari et al., 2008). Aluminum, cadmium, cobalt, copper, gold, lead, silver, and zinc are frequently used to create nanoparticles. Surface area-to-volume ratio, pore size, surface charge density, and high surface charge are some of the unique properties of these nanoparticles (Geetha et al., 2016). By altering the matching metal-based nanoparticles, metal oxide nanoparticles are created. Iron (Fe) nanoparticles oxidize to iron oxide at room temperature when oxygen is present. When their efficiency and reactivity rise, metal oxide nanoparticles are created (Tai et al., 2007). Zinc oxide, silicon dioxide, titanium oxide, iron oxide, magnetite, aluminum oxide, and cerium oxide. These tiny particles differ from the equivalent metals in a few special ways (Samy et al., 2022).

Organic nanoparticles are made of polymers such as liposomes, dendrimers, ferritin, and micelles. Drugs can be transported by these specific nanoparticles since they are non-toxic, and stable. Heat, light, and radiation sensitivity are associated with the hollow centers of liposomes and micelles, also known as nano-capsules (Tiwari et al., 2008, Gehrke et al., 2015). They are an effective drug delivery way because of these qualities. Because of their effectiveness, these kinds of nanoparticles are frequently employed in the field of medicine. Targeted drug delivery methods send nanoparticles to particular body parts. The material's composition, shape, size, flexibility, and surface quality all affect the attributes of nanoparticles (Muthu et al., 2009). Lipids and a wide variety of synthetic polymers made up of different substances make up nanoparticle composition. The most synthesized used polymers in the production of nanoparticles are dextran's, a polyanhydrides, and poly lactic-co-glycolic acid, and the nature polymer like elastin-like polypeptides. The production process, toxicity, and compatibility with loaded pharmaceuticals all influence the utilization of these nanoparticles (Macewan & Chilkoti, 2012). Shape and structure have an impact on nanoparticle efficiency as well. Spherical nanoparticles are less effective than rod-shaped nanoparticles at reaching specific tissues (Cao et al., 2019).

1.2.1. Application of Nanoparticles as a Treatment for Hydatid Disease

Much research has investigated the potential role of nanoparticles in treating cystic echinococcosis to inhibit the infective stage of *E. granulosus* (Norouzi et al., 2020). There are several nanoparticles are used as anti-cystic echinococcosis such as zinc oxide, copper, and silver (Shnawa, 2018).

The use of nanoparticles has many potential applications including targeted delivery of therapeutic agents which can improve the effectiveness of therapies against cystic echinococcosis. They are very tiny which helps them cross blood–brain barriers, and carry drugs specifically to infected organs and tissues, minimizing side effects. Such targeted therapy significantly enhances the efficacy of the treatment; it also reinforces the potential of these nanoparticles in the battle against this disease (Arshad et al., 2021, Malik et al., 2023). Research remains focused on innovative designs for nanoparticles aimed at enhancing drug release (Zhou et al., 2023, Wang et al., 2022). However, as this occurs, rules and regulations are evolving to safeguard patients while still permitting new ideas and inventions. These advancements could lead to improved treatment options for cystic echinococcosis and various infectious diseases. Although continued collaboration among researchers, clinicians and regulatory bodies is essential, achieving optimal therapeutic outcomes will require concerted effort (Casulli et al., 2022). It is essential to invest in nanoparticle research to bring out their characteristics. It is proposed that prospective studies must scrutinize both the long-term influences and specific duties in different patient groups in distinct healthcare sections.

Nanomedicine enhances the therapeutic efficacy by reducing side effects. Additionally, modifications can enhance drug delivery and retention within the cysts. Effective targeting is crucial for improving treatment outcomes and reducing the likelihood of drug resistance (Huang et al., 2022). Furthermore, tailored surface properties can facilitate better cellular uptake and release kinetics. These advancements promise to significantly improve the management of hydatid cyst infections and enhance overall patients' safety (Donahue et al., 2019).

To distribute praziquantel through nano-based delivery systems, the medication is encapsulated in a variety of nanomaterials, including copper, zinc, silver, gold, and zinc oxide, all of which are made of a combination of metals (Król et al., 2023, Boudier & Le Faou, 2023). Nanoparticles act as transporters and have the ability to enhance the outcomes of medication. Napooni et al. (2019) suggested that the Au nanoparticle can inhibit the protoscolies. The using of gold nanoparticles with praziquantel and albendazole for treating hydatid disease reduces the side effects that are produced by the chemical drugs and these two drugs will work better with nanoparticles. Jelowdar et al. (2017) recorded that chemoprophylaxis works better than praziquantel and albendazole in the treatment of cystic echinococcosis.

The silver nanoparticle (Ag) originated from the fungus named *Penicillium aculeatum* and has protoscolicidal properties and is safe and effective in the treating of echinococcosis, because it is nontoxic and has fewer side effects than albendazole (Rahimi et al., 2015, Nassef et al., 2019).

Lashkarizadeh et al. (2015) reported the protoscolicidal properties of Ag nanoparticles, essential oil of Foeniculum, amphotericin B, and hypertonic saline.

There are several advantages of using nanoparticles for treating of cystic echinococcosis such as due to their effective solubility, directed drug delivery, and they controlled the drug release (*Kesharwani et al., 2014,* El-Say & El-Sawy, 2017, *Pandian et al., 2021)*. The use of nanoencapsulated albendazoles and mebendazoles is a potential benzimidazole anthelmintic technique (*Shukla et al., 2021)*. Numerous nanostructured carriers, such as lipid nanoparticles, polymeric nanoparticles, and liposomes, have been used to encapsulate these medications (Shukla et al., 2021).

Nanoparticles have antiparasitic properties, like the triggering of apoptosis (Khashan et al., 2020, Ezzatkhah et al., 2021). Albendazole sulfoxide and albendazole sulfoxide-loaded poly (lactic-co-glycolic acid)-PEG was assessed against protoscoleces in an in vitro investigation by Naseri et al. (2016). According to Soltani et al. (2017), Solid lipid nanoparticles loaded with albendazole and albendazole sulfoxide had excellent physicochemical and controlled release characteristics. This suggests that the particles can function as extremely effective drug-delivery vehicles. These results imply that the treatment of cystic echinococcosis may benefit from the use of such materials.

1.2.2. Toxicity of Nanoparticles

Parasites are the most pathogenic microorganisms for humans and animals than other microorganisms because they cause chronic illness (Prajitha et al., 2019, Srivastava et al., 2021). Parasites have a complex life cycle and, therefore have the ability to live within the host and in the environment for many years (Gagne et al., 2022). Different parasite morphological stages result in different sensitivity to the same medication (Gupta & Xie, 2018). The continuous use of antiprotoscolixed which leads to resistance, and this issue is resolved by using nanoparticles which enhance the drug delivery (Rehman et al., 2021, Yin *et al*., 2022). Resistance to nanotherapeutics also occurred as antimicrobial resistance (Prajitha et al., 2019). There is proof that the environment that is produced by interactions between biological systems and nanoparticles aids in the development of resistance mechanisms within these systems (Wang et al., 2017). The nanoparticles can change the sensitivity of medication, which can aid in developing resistance to antibiotics (Chenthamara et al., 2019).

2. Discussion

The treatment of hydatid cysts with classical drugs is difficult and has several side effects (Manterola et al., 2023), first due to the location of cysts and it is difficult for drugs to reach it site or a low concentration of drug can be reached which results into a poor treatment outcome (Aminu et al., 2020), and second due to the cyst surrounded by a protective thick wall (Majumder et al., 2019). Therefore, nanotechnology and nanomedicine have the ability to enhance the delivery of drugs (Geramizadeh, 2017). Nanoparticles can be used with medication and encapsulated them increase their stability, solubility, and bioavailability cysts (Devadasu et al., 2013, Momčilović et al., 2019).

The early diagnosis and identification of cystic echinococcosis play an important role in the treatment of the disease. The most common diagnostic methods used for the diagnosis of hydatid cysts are ultrasound, and computed tomography, with aids of serological testing (AlGabbani, 2023). However, these methods may give a false negative result (Aljanabi et al., 2021). However, there is no sensitivity to using serological tests in the early diagnosis (Deng et al., 2019). Recently, the combination of nanotechnology with chemotherapy in the treatment of hydatid cysts has been successful (Cheraghipour et al., 2023). This is why nanotechnology developed (Ullio Gamboa et al., 2019). Also, resolved the problem of the solubility of the drugs by nanocarriers, and boosted the stability of the drugs (Muraleedharan & Chhabra, 2018). The main idea of the development of nanotechnology was that medication can reach the locations of cysts without any side effects, also, the drugs can be reached within the cysts effectively through nanocarriers by circulatory ways (Xu et al., 2022). This way is safer and more targeted (Nikam et al., 2022). The main problem of the classical treatment of echinococcosis was the development of resistance and is resolved by using nanocarriers (Şenel & Yüksel, 2020). The use of nanocarriers can postpone the process of the emergence of resistance.

Nanotechnology is a good technique for treating hydatid cysts, but still has some side effects such as their hazardous nature (Olawoyin, 2018). Several studies are required to determine the using nanoparticles and their effects on the human's health (Abdussalam-Mohammed, 2019). It is also important to monitor the hydatid cysts and resistance to nanotherapeutics. To avoid these researches are needed to do by using of different drugs from different classes should be combined with nanocarriers.

Conclusion

As known cystic hydatid disease is a zoonotic helminthic disease and it needs an early diagnosis and treatment. Classical medications have been developed drug resistance and this issue was resolved by introducing nanotechnology and nanomedicines. Nanotechnology and nanoparticles are recent developments used in the diagnosis and treatment of parasitic diseases. In the case of hydatid disease, the nanoparticles have efficient protoscolicidal properties and are used as antiprotoscolixes effects. More studies are necessary to comprehend the mechanisms of action of nanoparticles in order to create safe diagnostic and therapeutic alternatives.

References

Abdussalam-Mohammed, W. J. J. O. C. R. (2019). Review of therapeutic applications of nanotechnology in medicine field and its side

effects. *Journal of Chemical Reviews*, *1*(3), 243-251.
Adetunji, C.O., Egbuna, C., Oladosun, T.O., Akram, M., Micheal, O.S., Olisaka, F.N., Ozolua, P., Adetunji, J.B., Enoyoze, G.E., & Olaniyan, O.T. (2021). Neglected Tropical Diseases and Phytochemicals in Drug Discovery. John Wiley & Sons, Inc.; Hoboken, NJ, USA: Efficacy of Phytochemicals of Medicinal Plants for the Treatment of Human Echinococcosis: Echinococcal Disease, Hydatidosis, or Hydatid Disease Drug Discovery; pp. 225–243.
AlGabbani, Q. (2023). Nanotechnology: A promising strategy for the control of parasitic infections. *Experimental Parasitology*, *250*, 108548. https://doi.org/10.1016/j.exppara.2023.108548
Aljanabi, A. A., Al-Mussawi, K. A., & Bashi, A. M. (2021). Scolicidal effects of silver–copper (core-shell) nanoparticles against Echinococcus granulosus protoscolices in vitro. *Annals of the Romanian Society for Cell Biology*, 4335-4342.
Alshoabi, S. A., Alkalady, A. H., Almas, K. M., Magram, A. O., Algaberi, A. K., Alareqi, A. A., Hamid, A. M., Alhazmi, F. H., Qurashi, A. A., Abdulaal, O. M., Aloufi, K. M., Alsharif, W. M., Alsultan, K. D., Omer, A. M., & Gareeballah, A. (2023). Hydatid Disease: A Radiological Pictorial Review of a Great Neoplasms Mimicker. *Diagnostics (Basel, Switzerland)*, *13*(6), 1127. https://doi.org/10.3390/diagnostics13061127
Alvi, M. A., & Alsayeqh, A. F. (2022). Food-borne zoonotic echinococcosis: A review with special focus on epidemiology. *Frontiers in Veterinary Science*, *9*, 1072730. https://doi.org/10.3389/fvets.2022.1072730
Alvi, M. A., Ali, R. M. A., Khan, S., Saqib, M., Qamar, W., Li, L., Fu, B. Q., Yan, H. B., & Jia, W. Z. (2023). Past and present of diagnosis of echinococcosis: A review (1999-2021). *Acta Tropica*, *243*, 106925. https://doi.org/10.1016/j.actatropica.2023.106925
Aminu, N., Bello, I., Umar, N.M., Tanko, N., Aminu, A., & Audu, M.M. (2020). The influence of nanoparticulate drug delivery systems in drug therapy. *Journal of Drug Delivery Science and Technology, 60*:101961
Arshad, R., Gulshad, L., Haq, I. U., Farooq, M. A., Al-Farga, A., Siddique, R., Manzoor, M. F., & Karrar, E. (2021). Nanotechnology: A novel tool to enhance the bioavailability of micronutrients. *Food Science & Nutrition*, *9*(6), 3354–3361. https://doi.org/10.1002/fsn3.2311
Borhani, M., Fathi, S., Darabi, E., Jalousian, F., Simsek, S., Ahmed, H., Kesik, H. K., Hosseini, S. H., Romig, T., Harandi, M. F., & Mobedi, I. (2021). Echinococcoses in Iran, Turkey, and Pakistan: Old Diseases in the New Millennium. *Clinical Microbiology Reviews*, *34*(3), e0029020. https://doi.org/10.1128/CMR.00290-20
Boudier, A., & Le Faou, A. (2023). Nanoparticles and Other Nanostructures and the Control of Pathogens: From Bench to Vaccines. *International Journal of Molecular Sciences*, *24*(10), 9063. https://doi.org/10.3390/ijms24109063
Budke, C. M., Deplazes, P., & Torgerson, P. R. (2006). Global socioeconomic impact of cystic echinococcosis. *Emerging Infectious Diseases*, *12*(2), 296–303. https://doi.org/10.3201/eid1202.050499
Calame, P., Weck, M., Busse-Cote, A., Brumpt, E., Richou, C., Bresson-Hadni, S., & Delabrousse, E. (2022). Role of the radiologist in the diagnosis and management of the two forms of hepatic echinococcosis. *Insights into Imaging*, *13*(1), 68. https://doi.org/10.1186/s13244-022-01190-y
Cao, J., Choi, J.S., Oshi, M.A., Lee, J., Hasan, N., & Kim, J. (2019). Development of PLGA micro-and nanorods with high capacity of surface ligand conjugation for enhanced targeted delivery. *Asian Journal of Pharmaceutical Sciences, 14*(1),86–94.
Caraiani, C., Yi, D., Petresc, B., & Dietrich, C. (2020). Indications for abdominal imaging: When and what to choose? *Journal of Ultrasonography*, *20*(80), e43–e54. https://doi.org/10.15557/JoU.2020.0008
Casulli, A., Massolo, A., Saarma, U., Umhang, G., Santolamazza, F., & Santoro, A. (2022). Species and genotypes belonging to *Echinococcus granulosus sensu lato complex* causing human cystic echinococcosis in Europe (2000-2021): a systematic review. *Parasites & Vectors*, *15*(1), 109. https://doi.org/10.1186/s13071-022-05197-8
Chai, J. Y., Jung, B. K., & Hong, S. J. (2021). Albendazole and Mebendazole as Anti-Parasitic and Anti-Cancer Agents: an Update. *The Korean Journal of Parasitology*, *59*(3), 189–225. https://doi.org/10.3347/kjp.2021.59.3.189
Checkley, W., White, A. C., Jr, Jaganath, D., Arrowood, M. J., Chalmers, R. M., Chen, X. M., Fayer, R., Griffiths, J. K., Huston, C. D., Kotloff, K. L., Kang, G., Mead, J. R., Thompson, R. C., & Houpt, E. R. (2015). A review of the global burden, novel diagnostics, therapeutics, and vaccine targets for cryptosporidium. *The Lancet. Infectious Diseases*, *15*(1), 85–94. https://doi.org/10.1016/S1473-3099(14)70772-8
Chenthamara, D., Subramaniam, S., Ramakrishnan, S. G., Krishnaswamy, S., & Qoronfleh, M. W. (2019). Therapeutic efficacy of nanoparticles and routes of administration. *Biomaterials Research*, *23*, 20. https://doi.org/10.1186/s40824-019-0166-x
Cheraghipour, K., Azarhazine, M., Zivdari, M., Beiranvand, M., Shakib, P., Rashidipour, M., & Marzban, A. (2023). Evaluation of scolicidal potential of salicylate coated zinc nanoparticles against *Echinococcus granulosus* protoscoleces. *Experimental Parasitology*, *246*, 108456. https://doi.org/10.1016/j.exppara.2022.108456
Cho, E. J., Holback, H., Liu, K. C., Abouelmagd, S. A., Park, J., & Yeo, Y. (2013). Nanoparticle characterization: state of the art, challenges, and emerging technologies. *Molecular Pharmaceutics*, *10*(6), 2093–2110. https://doi.org/10.1021/mp300697h
Chouhan, M. D., Wiley, E., Chiodini, P. L., & Amin, Z. (2019). Hepatic alveolar hydatid disease (*Echinococcus multilocularis*), a mimic of liver malignancy: a review for the radiologist in non-endemic areas. *Clinical Radiology*, *74*(4), 247–256. https://doi.org/10.1016/j.crad.2019.01.007
Deng, M. H., Zhong, L. Y., Kamolnetr, O., Limpanont, Y., & Lv, Z. Y. (2019). Detection of helminths by loop-mediated isothermal amplification assay: a review of updated technology and future outlook. *Infectious Diseases of Poverty*, *8*(1), 20. https://doi.org/10.1186/s40249-019-0530-z
Devadasu, V. R., Bhardwaj, V., & Kumar, M. N. (2013). Can controversial nanotechnology promise drug delivery? *Chemical Reviews*, *113*(3), 1686–1735. https://doi.org/10.1021/cr300047q
Dietrich, C. F., Douira-Khomsi, W., Gharbi, H., Sharma, M., Cui, X. W., Sparchez, Z., Richter, J., & Yi, D. (2020). Cystic and alveolar echinococcosis of the hepatobiliary tract - the role of new imaging techniques for improved diagnosis. *Medical Ultrasonography*, *22*(1), 75–84. https://doi.org/10.11152/mu-2421

Diptyanusa, A., & Sari, I. P. (2021). Treatment of human intestinal cryptosporidiosis: A review of published clinical trials. *International journal for parasitology. Drugs and Drug Resistance*, *17*, 128–138. https://doi.org/10.1016/j.ijpddr.2021.09.001

Donahue, N. D., Acar, H., & Wilhelm, S. (2019). Concepts of nanoparticle cellular uptake, intracellular trafficking, and kinetics in nanomedicine. *Advanced Drug Delivery Reviews, 143*, 68–96. https://doi.org/10.1016/j.addr.2019.04.008

El-Say, K. M., & El-Sawy, H. S. (2017). Polymeric nanoparticles: Promising platform for drug delivery. *International Journal of Pharmaceutics*, *528*(1-2), 675–691. https://doi.org/10.1016/j.ijpharm.2017.06.052

Erfani, A., Shahriarirad, R., Eskandarisani, M., Rastegarian, M., & Sarkari, B. (2023). Management of Liver Hydatid Cysts: A Retrospective Analysis of 293 Surgical Cases from Southern Iran. *Journal of Tropical Medicine*, 9998739. https://doi.org/10.1155/2023/9998739

Ezzatkhah, F., Khalaf, A. K., & Mahmoudvand, H. (2021). Copper nanoparticles: Biosynthesis, characterization, and protoscolicidal effects alone and combined with albendazole against hydatid cyst protoscoleces. *Biomedicine & Pharmacotherapy = Biomedecine & Pharmacotherapie*, *136*, 111257. https://doi.org/10.1016/j.biopha.2021.111257

Gagne, R. B., Crooks, K. R., Craft, M. E., Chiu, E. S., Fountain-Jones, N. M., Malmberg, J. L., & VandeWoude, S. (2022). Parasites as conservation tools. *Conservation biology: the Journal of the Society for Conservation Biology*, *36*(1), e13719. https://doi.org/10.1111/cobi.13719

Geetha, P., Latha, M.S., Pillai, S.S., Deepa, B., Kumar, K.S., & Koshy, M. (2016). Green synthesis and characterization of alginate nanoparticles and its role as a biosorbent for Cr (VI) ions. *Journal of Molecular Structure, 1105*:54–60

Gehrke, I., Geiser, A., & Somborn-Schulz, A. (2015). Innovations in nanotechnology for water treatment. *Nanotechnology, Science and Applications*, *8*, 1–17. https://doi.org/10.2147/NSA.S43773

Geramizadeh, B. (2017). Isolated Peritoneal, Mesenteric, and Omental Hydatid Cyst: A Clinicopathologic Narrative Review. *Iranian Journal of Medical Sciences*, *42*(6), 517–523.

Gupta, R., & Xie, H. (2018). Nanoparticles in Daily Life: Applications, Toxicity and Regulations. *Journal of Environmental Pathology, Toxicology and Oncology: Official Organ of the International Society for Environmental Toxicology and Cancer*, *37*(3), 209–230. https://doi.org/10.1615/JEnvironPatholToxicolOncol.2018026009

Habibi, B., Gholami, S., Bagheri, A., Fakhar, M., Moradi, A., & Khazeei Tabari, M. A. (2023). Cystic echinococcosis microRNAs as potential noninvasive biomarkers: current insights and upcoming perspective. *Expert Review of Molecular Diagnostics*, *23*(10), 885–894. https://doi.org/10.1080/14737159.2023.2246367

Hasan, S. (2015). A review on nanoparticles: their synthesis and types. *Research Journal of Recent Sciences, 2277*:2502.

Huang, M., Zhang, M., Zhu, H., Du, X., & Wang, J. (2022). Mucosal vaccine delivery: A focus on the breakthrough of specific barriers. *Acta Pharmaceutica Sinica B*, *12*(9), 3456–3474. https://doi.org/10.1016/j.apsb.2022.07.002

Jelowdar A., Rafiei A., Abbaspour M.R., Rashidi I., & Rahdar M. (2017). Efficacy of combined albendazol and praziquntel and their loaded solid lipid nanoparticles components in chemoprophylaxis of experimental hydatidosis. *Asian Pacific Journal of Tropical Biomedicine, 7*, 549–554.

Karshima, S. N., Ahmed, M. I., Adamu, N. B., Magaji, A. A., Zakariah, M., & Mohammed, K. (2022). Africa-wide meta-analysis on the prevalence and distribution of human cystic echinococcosis and canine *Echinococcus granulosus* infections. *Parasites & Vectors*, *15*(1), 357. https://doi.org/10.1186/s13071-022-05474-6

Kern, P., Menezes da Silva, A., Akhan, O., Müllhaupt, B., Vizcaychipi, K. A., Budke, C., & Vuitton, D. A. (2017). The Echinococcoses: Diagnosis, Clinical Management and Burden of Disease. *Advances in Parasitology*, *96*, 259–369. https://doi.org/10.1016/bs.apar.2016.09.006

Kesharwani, P., Jain, K., & Jain, N.K. (2014). Dendrimer as nanocarrier for drug delivery. *Progress in Polymer Science*, 39(2):268–307. doi: 10.1016/j.progpolymsci.2013.07.005.

Khalili, N., Iranpour, P., Khalili, N., & Haseli, S. (2023). Hydatid Disease: A Pictorial Review of Uncommon Locations. *Iranian Journal of Medical Sciences*, *48*(2), 118–129. https://doi.org/10.30476/IJMS.2022.93123.2442

Khashan, K. S., Sulaiman, G. M., Hussain, S. A., Marzoog, T. R., & Jabir, M. S. (2020). Synthesis, characterization and evaluation of anti-bacterial, anti-parasitic and anti-cancer activities of aluminum-doped zinc oxide nanoparticles. *Journal of Inorganic and Organometallic Polymers and Materials*, *30*(9), 3677-3693.

Król, G., Fortunka, K., Majchrzak, M., Piktel, E., Paprocka, P., Mańkowska, A., Lesiak, A., Karasiński, M., Strzelecka, A., Durnaś, B., & Bucki, R. (2023). Metallic Nanoparticles and Core-Shell Nanosystems in the Treatment, Diagnosis, and Prevention of Parasitic Diseases. *Pathogens (Basel, Switzerland)*, *12*(6), 838. https://doi.org/10.3390/pathogens12060838

Lashkarizadeh, M. R., Asgaripour, K., Saedi Dezaki, E., & Fasihi Harandi, M. (2015). Comparison of Scolicidal Effects of Amphotricin B, Silver Nanoparticles, and Foeniculum vulgare Mill on Hydatid Cysts Protoscoleces. *Iranian Journal of Parasitology*, *10*(2), 206–212.

Lupia, T., Corcione, S., Guerrera, F., Costardi, L., Ruffini, E., Pinna, S. M., & Rosa, F. G. (2021). Pulmonary Echinococcosis or Lung Hydatidosis: A Narrative Review. *Surgical Infections*, *22*(5), 485–495. https://doi.org/10.1089/sur.2020.197

Macewan, S. R., & Chilkoti, A. (2012). Digital switching of local arginine density in a genetically encoded self-assembled polypeptide nanoparticle controls cellular uptake. *Nano Letters*, *12*(6), 3322–3328. https://doi.org/10.1021/nl301529p

Machado, S., Pacheco, J. G., Nouws, H. P., Albergaria, J. T., & Delerue-Matos, C. (2015). Characterization of green zero-valent iron nanoparticles produced with tree leaf extracts. *The Science of the Total Environment*, *533*, 76–81. https://doi.org/10.1016/j.scitotenv.2015.06.091

Majumder, J., Taratula, O., & Minko, T. (2019). Nanocarrier-based systems for targeted and site specific therapeutic delivery. *Advanced Drug Delivery Reviews*, *144*, 57–77. https://doi.org/10.1016/j.addr.2019.07.010

Malik, S., Muhammad, K., & Waheed, Y. (2023). Nanotechnology: A Revolution in Modern Industry. *Molecules (Basel, Switzerland)*, *28*(2), 661. https://doi.org/10.3390/molecules28020661

Manterola, C., Rivadeneira, J., Pogue, S.D., & Rojas, C. (2023). Morphology of Echinococcus granulosus Protoscolex. *International Journal of Morphology, 41*:646–653. doi: 10.4067/S0717-95022023000200646

Meftahi, G. H., Bahari, Z., Zarei Mahmoudabadi, A., Iman, M., & Jangravi, Z. (2021). Applications of western blot technique: From bench to bedside. *Biochemistry and Molecular Biology Education: A Bimonthly Publication of the International Union of Biochemistry and Molecular Biology*, *49*(4), 509–517. https://doi.org/10.1002/bmb.21516

Mishra, S. (2016). Nanotechnology in medicine. *Indian Heart Journal*, *68*(3), 437–439. https://doi.org/10.1016/j.ihj.2016.05.003

Momčilović, S., Cantacessi, C., Arsić-Arsenijević, V., Otranto, D., & Tasić-Otašević, S. (2019). Rapid diagnosis of parasitic diseases: current scenario and future needs. *Clinical Microbiology and Infection: The Official Publication of the European Society of Clinical Microbiology and Infectious Diseases*, *25*(3), 290–309. https://doi.org/10.1016/j.cmi.2018.04.028

Moro, P., & Schantz, P. M. (2009). Echinococcosis: a review. *International Journal of Infectious Diseases: IJID: Official Publication of the International Society for Infectious Diseases*, *13*(2), 125–133. https://doi.org/10.1016/j.ijid.2008.03.037

Muraleedharan, K., & Chhabra, M. (2018). Nanotechnology applications and potential in parasitology: An overview. *Journal Veterinary Immunology & Biotechnology, 1*, 25-40.

Muthu, M. S., Rawat, M. K., Mishra, A., & Singh, S. (2009). PLGA nanoparticle formulations of risperidone: preparation and neuropharmacological evaluation. *Nanomedicine: Nanotechnology, Biology, and Medicine*, *5*(3), 323–333. https://doi.org/10.1016/j.nano.2008.12.003

Napooni, S., Delavari, M., Arbabi, M., Barkheh, H., Rasti, S., Hooshyar, H., & Mostafa Hosseinpour Mashkani, S. (2019). Scolicidal Effects of Chitosan-Curcumin Nanoparticles on the Hydatid Cyst Protoscolices. *Acta Parasitologica*, *64*(2), 367–375. https://doi.org/10.2478/s11686-019-00054-8

Naseri, M., Akbarzadeh, A., Spotin, A., Akbari, N. A., Mahami-Oskouei, M., & Ahmadpour, E. (2016). Scolicidal and apoptotic activities of albendazole sulfoxide and albendazole sulfoxide-loaded PLGA-PEG as a novel nanopolymeric particle against Echinococcus granulosus protoscoleces. *Parasitology Research*, *115*(12), 4595–4603. https://doi.org/10.1007/s00436-016-5250-8

Nassef, N. E., Saad, A. E., Harba, N. M., Beshay, E. V. N., Gouda, M. A., Shendi, S. S., & Mohamed, A. S. E. (2019). Evaluation of the therapeutic efficacy of albendazole-loaded silver nanoparticles against *Echinococcus granulosus* infection in experimental mice. *Journal of Parasitic Diseases: Official Organ of the Indian Society for Parasitology*, *43*(4), 658–671. https://doi.org/10.1007/s12639-019-01145-z

Nikam, P. B., Salunkhe, J. D., Minkina, T., Rajput, V. D., Kim, B. S., & Patil, S. V. (2022). A review on green synthesis and recent applications of red nano Selenium. *Results in Chemistry*, *4*, 100581.

Norouzi, R., Ataei, A., Hejazy, M., Noreddin, A., & El Zowalaty, M. E. (2020). Scolicidal Effects of Nanoparticles against Hydatid Cyst Protoscolices in vitro. *International Journal of Nanomedicine*, *15*, 1095–1100. https://doi.org/10.2147/IJN.S228538

Olawoyin, R. (2018). Nanotechnology: The future of fire safety. *Safety Science*, *110*, 214-221.

Pandian, S.R.K., Panneerselvam, T., Pavadai, P., Govindaraj, S., Ravishankar, V., Palanisamy, P., Sampath, M., Sankaranarayanan, M., & Kunjiappan, S. (2021). Nano based approach for the treatment of neglected tropical diseases. *Frontiers in Nanotechnology*, 3:665274.

Paramita, A.A., & Wibawa, I.D. (2023). Multimodal Treatment of Cystic Echinococcosis. *The Indonesian Journal of Gastroenterology, Hepatology, and Digestive Endoscopy*, *24:72–82*. https://doi.org/10.24871/241202372-82

Prajitha, N., Athira, S. S., & Mohanan, P. V. (2019). Bio-interactions and risks of engineered nanoparticles. *Environmental Research*, *172*, 98–108. https://doi.org/10.1016/j.envres.2019.02.003

Prasad, R.D., Charmode, N., Shrivastav, O.P., Prasad, S.R., Moghe, A., Sarvalkar, P.D., & Prasad, N.R. (2021). A review on concept of nanotechnology in Veterinary Medicine. *ES Food and Agroforestry, 4*, 28–60.

Rahimi, M. T., Ahmadpour, E., Rahimi Esboei, B., Spotin, A., Kohansal Koshki, M. H., Alizadeh, A., Honary, S., & Ali Mohammadi, M. (2015). Scolicidal activity of biosynthesized silver nanoparticles against *Echinococcus granulosus* protoscolices. *International Journal of Surgery (London, England)*, *19*, 128–133. https://doi.org/10.1016/j.ijsu.2015.05.043

Rehman, A.U., Nazir, S., Irshad, R., Tahir, K., Rehman, K., Islam, R.U., & Wahab, Z. (2021). Toxicity of heavy metals in plants and animals and their uptake by magnetic iron oxide nanoparticles. *Journal of Molecular Liquids*, 321, 114455

Rossignol, J. F., Kabil, S. M., el-Gohary, Y., & Younis, A. M. (2006). Effect of nitazoxanide in diarrhea and enteritis caused by Cryptosporidium species. *Clinical Gastroenterology and Hepatology: the Official Clinical Practice Journal of the American Gastroenterological Association*, *4*(3), 320–324. https://doi.org/10.1016/j.cgh.2005.12.020

Sadr, S., Poorjafari Jafroodi, P., Haratizadeh, M. J., Ghasemi, Z., Borji, H., & Hajjafari, A. (2023). Current status of nano-vaccinology in Veterinary Medicine Science. *Veterinary Medicine and Science*, *9*(5), 2294–2308. https://doi.org/10.1002/vms3.1221

Sahu, T., Ratre, Y.K., Chauhan, S., Bhaskar, L., Nair, M.P., & Verma, H.K. (2021). Nanotechnology based drug delivery system: Current strategies and emerging therapeutic potential for medical science. *Journal of Drug Delivery Science and Technology, 63*, 102487.

Salavati-Niasari, M., Davar, F., & Mir, N. (2008). Synthesis and characterization of metallic copper nanoparticles via thermal decomposition. *Polyhedron*, *27*(17), 3514–18.

Samy, A., Hassan, H.U., & Elsherif, H. (2022). Effect of Nano Zinc Oxide and Traditional Zinc (Oxide and Sulphate) Sources on Performance, Bone Characteristics and Physiological Parameters of Broiler Chicks. *International Journal of Veterinary Science, 11*(4):486–92.

Şenel, S., & Yüksel, S. (2020). Chitosan-based particulate systems for drug and vaccine delivery in the treatment and prevention of neglected tropical diseases. *Drug Delivery and Translational Research*, *10*(6), 1644–1674. https://doi.org/10.1007/s13346-020-00806-4

Shnawa, B. H. (2018). Advances in the use of nanoparticles as anti-cystic echinococcosis agents: A review article. *Journal of Pharmaceutical Research International*, *24*(1), 1-14.

Shukla, R., Mourya, A., Handa, M., & Ujjwal, R.R. (2021). Nanopharmaceutical Advanced Delivery Systems. Scrivener Publishing; Beverly, MA, USA: Role of nanomedicines in neglected tropical diseases; pp. 407–446.

Sindhwani, S., & Chan, W. C. W. (2021). Nanotechnology for modern medicine: next step towards clinical translation. *Journal of Internal Medicine, 290*(3), 486–498. https://doi.org/10.1111/joim.13254

Soltani, S., Rafiei, A., Ramezani, Z., Abbaspour, M.R., Jelowdar, A., & Kahvaz, M.S. (2017). Evaluation of the hydatid cyst membrane permeability of albendazole and albendazole sulfoxide-loaded solid lipid nanoparticles. *Jundishapur Journal of Natural Pharmaceutical Products*, 12, e34723.

Srivastava, S., Usmani, Z., Atanasov, A. G., Singh, V. K., Singh, N. P., Abdel-Azeem, A. M., Sharma, M., & Bhargava, A. (2021). Biological Nanofactories: Using Living Forms for Metal Nanoparticle Synthesis. *Mini Reviews in Medicinal Chemistry*, *21*(2), 245–265. https://doi.org/10.2174/1389557520999201116163012

Taghipour, A., Ghaffarifar, F., Horton, J., Dalimi, A., & Sharifi, Z. (2021). Silybum marianum ethanolic extract: in vitro effects on protoscolices of *Echinococcus granulosus* G1 strain with emphasis on other Iranian medicinal plants. *Tropical Medicine and Health*, *49*(1), 71. https://doi.org/10.1186/s41182-021-00363-7

Tai, C.Y., Tai, C.T., Chang, M.H., & Liu, H.S. (2007). Synthesis of magnesium hydroxide and oxide nanoparticles using a spinning disk reactor. *Industrial & Engineering Chemistry Research, 46*(17), 5536–41.

Tiwari, D.K., Behari, J., & Sen, P. (2008). Application of nanoparticles in waste water treatment. *World Applied Sciences Journal, 3*(3), 417–33.

Ullio Gamboa, G. V., Pensel, P. E., Elissondo, M. C., Sanchez Bruni, S. F., Benoit, J. P., Palma, S. D., & Allemandi, D. A. (2019). Albendazole-lipid nanocapsules: Optimization, characterization and chemoprophylactic efficacy in mice infected with Echinococcus granulosus. *Experimental Parasitology*, *198*, 79–86. https://doi.org/10.1016/j.exppara.2019.02.002

Wang, D., Wu, J., Wang, Y. *et al.* (2020). Finding High-Quality Groundwater Resources to Reduce the Hydatidosis Incidence in the Shiqu County of Sichuan Province, China: Analysis, Assessment, and Management. *Expo Health, 12*, 307–322 https://doi.org/10.1007/s12403-019-00314-y

Wang, L., Hu, C., & Shao, L. (2017). The antimicrobial activity of nanoparticles: present situation and prospects for the future. *International Journal of Nanomedicine*, *12*, 1227–1249. https://doi.org/10.2147/IJN.S121956

Wang, S., Ma, Y., Wang, W., Dai, Y., Sun, H., Li, J., Wang, S., & Li, F. (2022). Status and prospect of novel treatment options toward alveolar and cystic echinococcosis. *Acta Tropica*, *226*, 106252. https://doi.org/10.1016/j.actatropica.2021.106252

Wen, H., Vuitton, L., Tuxun, T., Li, J., Vuitton, D. A., Zhang, W., & McManus, D. P. (2019). Echinococcosis: Advances in the 21st Century. *Clinical Microbiology Reviews*, *32*(2), e00075-18. https://doi.org/10.1128/CMR.00075-18

Xu, X., Qian, X., Gao, C., Pang, Y., Zhou, H., Zhu, L., Wang, Z., Pang, M., Wu, D., Yu, W., Kong, F., Shi, D., Guo, Y., & Fan, H. (2022). Advances in the pharmacological treatment of hepatic alveolar echinococcosis: From laboratory to clinic. *Frontiers in Microbiology*, *13*, 953846. https://doi.org/10.3389/fmicb.2022.953846

Yin, B., Sun, W., Zhang, X., & Liew, K. (2022). Deciphering structural biological materials: Viewing from the mechanics perspective and their prospects. *Composites Part B: Engineering*, 245, 110213.

Zhang, W., Li, J., & McManus, D. P. (2003). Concepts in immunology and diagnosis of hydatid disease. *Clinical Microbiology Reviews*, *16*(1), 18–36. https://doi.org/10.1128/CMR.16.1.18-36.2003

Zhang, W., Wen, H., Li, J., Lin, R., & McManus, D. P. (2012). Immunology and immunodiagnosis of cystic echinococcosis: an update. *Clinical & Developmental Immunology*, *2012*, 101895. https://doi.org/10.1155/2012/101895

Zhou, Z., Kai, M., Wang, S., Wang, D., Peng, Y., Yu, Y., Gao, W., & Zhang, L. (2023). Emerging nanoparticle designs against bacterial infections. *Wiley interdisciplinary reviews. Nanomedicine and Nanobiotechnology*, *15*(4), e1881.

Zhu, X., Radovic-Moreno, A. F., Wu, J., Langer, R., & Shi, J. (2014). Nanomedicine in the Management of Microbial Infection - Overview and Perspectives. *Nano Today*, *9*(4), 478–498. https://doi.org/10.1016/j.nantod.2014.06.003