The Role of Nano Medicine in Controlling Vector-borne Diseases of Veterinary Importance

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Abstract

The veterinary profession has come along some tremendous advancements in terms of disease diagnosis, treatment and prevention. However, some health issues are still posing major hurdles in animals' well-being. Among these, vector-borne diseases pose major challenges for veterinary care, impact animal welfare, and cause significant financial losses worldwide. The inefficiency, environmental problems, and the emergence of resistance lead to the failure of disease and vector control strategies. This chapter is focused on the revolutionary potential of nanomedicine in resolving these therapeutic issues. The detection, prevention, control and management of vector-borne diseases are the application of nanotechnology due its unique mechanisms and nanoscale materials. The enhanced stability, immunity, and extended diffusion ability are the major concerns that lead to application of nanoscale materials in the development of nanovaccines. In this chapter we will emphasizes the significance of nanotechnology in enhancing the animal health and promoting innovative strategies of preventing and treating the vector borne diseases of veterinary importance.

Keywords: Nanotechnology, Vector-borne diseases, Nanomedicine, Nanoscale materials, Nano vaccines, Nano diagnostics, Nanotherapeutics

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Introduction

Vector-borne diseases are a significant issue in veterinary medicine and affect the variety of animals, including food producing ani/mals as well as companion animals. The flies, mosquitos, and ticks are the major vectors that pose a global threat to animal health and results in significant financial losses for the livestock sector. All these vectors play major role in spreading of vector-borne diseases like babesiosis, anaplasmosis, theileriosis, leishmaniosis, borreliosis, ehrlichiosis, and rickettsiosis. The most significant of these are caused by protozoan parasites and spread by tick vectors (Little, 2008). Numerous pathogens that are transmitted by arthropod vectors, such as sand flies, fleas, ticks, and mosquitoes, cause the broad category of illnesses known as vector-borne diseases (Dantas-Torres & Otranto, 2016). The global prominence given to the 'One Health' concept of coordinated activity of those involved in human and animal health is a modern manifestation of a long tradition of comparative medicine, which has roots in ancient civilizations and a golden age during the 19th century explosion of knowledge in the field of infectious disease research (Day, 2011).

The use of nanotechnology in the medical field, where nanoscale materials are employed to identify, treat, and prevent illnesses, is known as nanomedicine (Dey et al., 2022). Nanotechnology focuses on manipulating various instruments and practical materials at the nanoscale. In 1959, American Nobel laureate Richard Feynman first proposed the concept of nanotechnology (Prasad et al., 2021). Nanotechnology has transformed almost every area of veterinary and animal science and created new opportunities for applications in molecular biology and biotechnology by producing new, small-scale materials and techniques that are beneficial for living beings. Numerous types of nanomaterials are used in disease diagnosis and treatment, medicine delivery, animal nutrition, and animal breeding. Fullerenes, liposomes, dendrimers, carbon nanotubes, magnetic nanoparticles, metallic nanoparticles, and quantum dots are among the several types of nanoparticles that are used (Prasad et al., 2021).

Nanoparticles can interact with biological systems in ways that conventional treatments cannot because of their small size and surface characteristics. This chapter examines the mechanisms, uses, and potential future developments of nanomedicine in the management of vector-borne illnesses.

Overview of Vector-Borne Diseases in Veterinary Medicine

Vector-borne diseases are any of a broad category of infectious conditions caused by pathogens that are dispersed by arthropods or other biologic intermediaries. Although transmission usually occurs when an infected bug or acarine parasite feeds on blood, infection can also occur when a vertebrate host swallows a vector or when infectious organisms in the arthropod intermediate's excrement contaminate a wound. Worldwide, vector-borne illnesses still damage animals, leading to indirect ecological and economic effects in addition to direct health effects. These illnesses frequently necessitate significant care, control, and elimination efforts in the veterinary industry (Little, 2008).

Major Vector-Borne Diseases

Anaplasmosis

Cattle and other livestock are the main victims of anaplasmosis, a disease spread by ticks and caused by *Anaplasma spp*. Ticks like *Rhipicephalus* and *Ixodes spp*. are responsible for its transmission (Silaghi et al., 2017). Bovine anaplasmosis is an infectious but non-contagious disease caused by *Anaplasma marginale*. It spreads through tick bites, the mechanical transmission of fresh blood from infected calves to susceptible cattle by biting flies, or blood-contaminated equipment such as needles, ear tagging, dehorning, and castration tools. It can result in large losses in livestock productivity and manifest clinically as fever, anemia, and lethargy (Aubry & Geale, 2011).

Usually, the infection is diagnosed using serologic evidence of antibodies, and the diagnosis is then confirmed using molecular detection techniques. The timely vaccination, vector control, prophylactic antibiotics, and ensuring the anaplasmosis free herds are the effective strategies to control bovine anaplasmosis (Aubry & Geale, 2011).

Babesiosis

Babesiosis is a significant tick born disease which is brought on by protozoan parasites belonging to the *Babesia* genus and spread by ticks. It primarily affects the cattle and dogs causes symptoms like fever, jaundice, and severe anemia (Garcia et al., 2022). The protozoal, hemoparasitic disease known as canine babesiosis sprad by ticks and can result in thrombocytopenia, spleanomegaly, hemolytic anemia and severe fever in variable degree (Vishwakarma & Nandini, 2019).

An AgELISA that may be adopted for rapid diagnostic test design is presented for the early and precise diagnosis of acute infections while taking superior diagnostic methodologies into account (Irwin, 2009). Blood transfusions are used to treat the severe anemia, supportive therapy is used to restore the animal's health, antiprotozoal medicines are used to manage the parasites, and antibiotics are used to prevent secondary bacterial infection (Solano-Gallego & Baneth, 2011). Babesiosis is currently being controlled via vaccination against *Babesia spp.*, particularly *B.gibsoni*, in addition to preventive measures. Along with the prophylactic measures the vaccines against *Babesia spp*., including *B. gibsoni*, are now being developed and administered to control babesiosis (Boozer & Macintire, 2003).

Theileriosis

The cattle and buffalo are most susceptible species to theileriosis which is transmitted by *Hyalomma* ticks. The swollen lymph nodes, anemia and fever are the manifestation of theileriosis which is brought on by parasites called *Theileria*. The fate of untreated animals is death in severe cases (Tilahun, 2016). The two most virulent and significant from commercial point of view are *T. annulate* and *T. parva*, that causes the tropical theileriosis and East Cost fever, respectively. The ixodid tick's species of *Hyalomma* and *Rhipicephalus* are the major vectors of tropical theileriosis and east coast fever, respectively (Kasozi et al., 2014). Bovine theileriosis has a major global economic impact on livestock sector, prophylaxis is the best strategy to lower disease-related losses (Bhatnagar et al., 2015). The second most effective strategy to reduce the tick load is the use of chemicals acaricides is widely used worldwide. The selection of tick resistant cattle breeds is the most effective and cheapest tick control strategy for controlling the tick born infections in developing nations (Abdela & Bekele, 2016).

Vectors

The term "Vector-Borne" is frequently used to describe ta variety of pathogens and parasites that cause the most dangerous diseases in humans, animals, and the environment (Wilson et al., 2017). Flies, ticks, and mosquitoes are the major carriers of these problems. Tick transmit the babesiosis and theileriosis which are two tick-borne diseases. On the other hand, heartworm disease which affects both food producing animals as well as pets is spread by mosquitoes (Getahun et al., 2022).

Challenges in Traditional Disease Control

The traditional vector control strategies include the use of chemical pesticides, insecticides, and vaccinations. Among the several challenges that these strategies must overcome are the the development of vector resistance, environmental issues related to pesticide use, and the high expense of immunization programs (Garros et al., 2018). As a result of the demand for more targeted, efficient, and sustainable solutions alternative methodologies like use of nanomedicine, are being investigated to control these problems.

Basics of Nanomedicine and its Mechanisms in Disease Control

Nanomedicine is the application of use of nanotechnology in medicine to use nanomaterials for disease prevention, diagnosis, and treatment. Because of their novel properties such as their small size, large surface area, and ability to interact with biological systems at cellular and molecular levels, nanomaterials are very useful for medical applications, including veterinary science (Auría-Soro et al., 2019). The use of nanomedicine has been linked with target-specific drug delivery using nanoparticle formulations including liposomes, SLNs, and fullerenes, among others, and sensitive disease diagnosis using quantum dots, and magnetic nanoparticle. Furthermore, a number of nanoparticles are being investigated as potential adjuvants that can increase the efficacy of antigen presentation and prolong immunity (Mohantya et al., 2014). Nanotechnology is an emerging scientific and technical subject that has led to new and innovative techniques in many areas of medicine. Even though they were new, Richard P. Feynman foresaw the development of nanomaterials in 1959. Nanotechnology is an emerging scientific and technical subject that has led to new and innovative techniques in many areas of medicine.

Although novel, Richard P. Feynman predicted the emergence of nanomaterials as early as 1959 (Appenzeller et al., 1991). Nanotechnology is the measurement, manipulation, and organization of materials at the tiny level. Materials smaller than 1 µm are commonly included in the scale, even though it usually refers to matter between 1 and 100 nm in size. Advances in nanotechnology have led to the creation of new nanostructures that differ from their bigger counterparts in terms of physiochemical properties and surface-to-volume ratio (Mody et al., 2010). Nanoscale biological processes are therefore excellent prospects for biomedical applications due to their diversity (Chauhan et al., 2010). Despite the fact that nanomedicine is still in its early stages and its application in the veterinary field may appear impossible, many researchers have shown promise. Nanotechnology is currently being used to treat African animal trypanosomiasis (Kroubi et al., 2010). Nanotechnology is expected to not only transform veterinary medicine but also help practitioners understand and use these technologies. Nanomedicine has the potential to be a tool for solving the issues facing modern medicine, in addition to providing endless access to knowledge about the fundamental operations of the biological system (Mohantya et al., 2014).

Types of Nanomaterials Used in Veterinary Applications

Nanoparticles: Metals, polymers, or lipids can be used to create these most widely used nanomaterials. They can be designed to administer medications or vaccines precisely (Kiruthika & Bhattacharya, 2024). These developments could lessen pain, hasten the healing of wounds, and protect our patients from viral or bacterial infections. Furthermore, these new molecules might more accurately transport drugs and DNA. Since these systems will influence how rapidly drugs or other chemicals are absorbed, transported, metabolized, and eliminated in the body, we can control the drug dynamics (Table 1) (Underwood et al., 2012).

Polymeric nanoparticles are made by combining an active molecule with a polymer. The active components are adsorbed or trapped on the surface of the polymer nanoparticle. Both natural and synthetic polymers are used in a variety of polymeric nanoparticle forms. It is simple to construct and improve polymer delivery properties, surface features, shape, and composition in order to provide the necessary drug loading, biocompatibility, targeting, degradation, and controlled release kinetics (Yang & Alexandridis, 2000).

Table 1: Here are some instances of nanoparticles that are being studied, tested, or authorized for use in animals, along with their likely uses in human and veterinary medicine (Underwood et al., 2012).

Sr.No	Nanocarriers	Veterinary Application	Animal under trail
1	Magnetic nanoparticles	MRI contrast, drug delivery (Kim et al., 2012)	Cats. (Underwood et al., 2012)
2	Liposomes	Therapeutics (Underwood et al., 2012)	Cattle, dogs, horse, Cats, birds, sheep. (Underwood et al., 2012)
3	Nanoemulsion	Drug delivery and therapeutics	Dogs, Cats (Underwoodetal., 2012)
4	Nanosphere	Vaccine delivery	Horse (Underwood et al., 2012)
5	Micelle	Therapeutics	Sheep, birds, horse. (Underwood et al., 2012)
6	Dentrimers	Microbicide and vaccine delivery (Kim et al., 2010)	Pigs (Underwood et al., 2012)
7	Quantum dot	Fluorescent contrast, invitro diagnostics (Kim et al., 2010)	Cats. (Underwood et al., 2012)
8	Gold nanoparticles	In-vitro diagnosis (Kim et al., 2010)	Cats. (Underwood et al., 2012)

Liposomes: Both hydrophilic and hydrophobic molecules can be encapsulated in liposomes, which are spherical vesicles made of lipid bilayers. They have been employed in vaccine development and medication delivery (Bibi et al., 2024). Liposomes are vesicles with an aqueous core surrounded by one or more phospholipid bilayers. Both hydrophilic and hydrophobic compounds can be transported by liposomes, making them extremely versatile delivery vehicles. By conjugating to ligands or antibodies, they can be altered to optimize their suitability for a particular function. Liposomes are rarely suitable for oral use because of their vulnerability to gastrointestinal system breakdown, despite the fact that they can be used topically, intravenously, and intramuscularly (Bakker-Woudenberg et al., 2005).

They have been investigated for targeted drug delivery, gene delivery, immunization, and imaging agents with promising outcomes. In addition to customized drug delivery, liposomes are used in the treatment of cancer. Liposomes with a reasonable shelf life are now available and an affordable option for veterinary therapy due to increased liposome production for commercial use (Mohantya et al., 2014).

Dendrimers: These are nanoscale, highly branched molecules that can be functionalized to act as diagnostic agents or medication delivery systems (Sarode & Mahajan, 2024). Spherical in shape, dendrimer forms have a high molecular weight but a small molecular size, and their branch lengths are constrained by steric constraints. These structures carry medications in two ways: (a) by attaching themselves to functional groups on the surface of the dendrimer, and (b) by encasing the medications in the dendritic channels of the sphere.

One example is the development of dendrimers using polymers such as polyamidoamine (PAMAM), which provide stability, availability, and tolerability (Baker et al., 2001). Researchers think dendrimers could perform a five-step procedure for treating tumors: (i) they could find tumor cells all over the body by looking for tumor receptors; (ii) they could attach to and cross cell membranes; (iii) they could perform a chemical analysis inside the cells to inform veterinarians about the type of tumors that are present in the animal's body; (v) they could chemically verify that the process killed the cells; and (iv) they could release radioactive agents or chemotherapy inside the tumor cells (Feneque, 2003).

Solid Lipid Nanoparticles (SLNs): SLN are composed of lipids that are solid at room temperature, stabilized by a surfactant, and suspended in an aqueous solution. The therapeutic component is dissolved or dispersed inside the lipid (Mishra et al., 2010). Moreover, drugs that are hydrophobic stay stable in their lipid matrix. They have low levels of toxicity and can be made without the use of organic solvents. SLN's special capacity to transport drugs across the blood-brain barrier can impact drug delivery to the brain in a number of ways (Muller & Keck, 2004).

Mechanisms of Nanomedicine in Disease Control

Targeted Drug Delivery: To improve therapeutic effectiveness and reduce adverse effects, nanoparticles can be engineered to deliver medications precisely to infected cells or tissues (Ali et al., 2021). One of the veterinary medical areas that would benefit the most from research on nanotechnology is pharmacology. Since these systems will influence how rapidly drugs or other chemicals are absorbed, transported, metabolized, and eliminated in the body, we can control the drug dynamics (Underwood et al., 2012).

Diagnostics: Controlling vector-borne diseases requires the development of very sensitive diagnostic tools for early disease detection, which is made possible by nanotechnology (Hazra & Patra, 2023). Because nanotechnology operates at the same scale as a virus or other disease-infecting particle, it holds the potential for incredibly early diagnosis and eradication (Jain, 2005).

Vaccine Delivery: By preserving the active ingredients, boosting immune responses, and guaranteeing stable distribution, nanoparticles can enhance vaccine delivery (Liang et al., 2024). The production of a long-lasting and protective antibody against a pathogen is the primary objective of vaccine science; the adjuvant and antigen are crucial components of this process. Safer synthetic and recombinant alternatives have replaced the old vaccination method's use of living and dead organisms. Although there are several novel antigen-carrying methods available with the advent of nanotechnology, traditional adjuvants cannot be tunneled (Nordly et al., 2009). These adjuvants based on nanoparticles can be made to have a reduced dose frequency and an easy way of administration in order to trigger a target-specific immune response. To enhance target mucosal immunity, for instance, the intranasal approach can be employed. As a result, they are perfect for veterinary species where multiple animals may need treatment simultaneously or when standard immunization techniques are difficult due to complex management systems or restricted accessibility (Underwood et al., 2012).

By mimicking pathogen-associated molecular patterns, upregulating co-stimulatory molecules on antigen-presenting cells, maintaining immunity, delivering antigens for a prolonged duration, and, finally, creating virus-like particles that mimic a virus's capsid and elicit immune responses without the infectious agent, adjuvants for nanoparticles increase a vaccine's immunogenicity (Mohantya et al., 2014).

Application of Nanomedicine in Vector Control

With cutting-edge tools like nanopesticides and repellents, nanomedicine provides intriguing ways to directly control vector populations, including mosquitoes and ticks.

Nano pesticides: Insecticides that have been developed at the nanoscale to increase their efficacy, decrease their toxicity, and prolong their duration of action are known as nano insecticides. Targeting and controlling the disease-transmitting vectors in their environment is possible with these (De et al., 2014). For instance, compared to traditional insecticides, nano silver and nano sulfur are more effective at killing ticks and mosquitos with less of detrimental environmental impacts (Abdollahdokht et al., 2022). The gap enables the use of nanotechnology and application of nano pesticides. The two main categories of nanopesticides are man-made and biological nanopesticides. Insect growth regulators, conventional insecticides, and other microbial control agents are used to prevent mosquitoes from growing and spreading. Among the innovative nano formulations that exhibit the potential as nano pesticides are nanoparticles made from plant extracts, nano emulsions containing pesticides like pyrethroids, nano emulsions containing essential oils like citronella and neem. Despite the overwhelming evidence that these nano insecticides are effective, limited research is done to examine the impacts of these substances on the life of other aquatic species. The advantages of these chemical over the conventional pesticides include their efficacy and limited adverse effects on environment (Mishra et al., 2018).

Nano Repellents: The particular compositions used to keep vectors like mosquitos away from the animals are called nano repellents. These repellents are commonly in long-lasting, slow release formulations that provide extended protection with fewer treatments (Basu & Bhattacharya, 2021). According to reports, nanomodified permethrin exhibits better larvicidal activity, shelf life, and target specificity against *Aedes (Ae.) aegypti* with minimal impact on non-target organisms than the bulk version of water-insoluble permethrin currently available on the market. These tiny, delicate particles' capacities to penetrate the negatively charged outer biological membrane of mosquito larvae reduces the quantity of active chemicals required (Ghormade et al., 2011).

Additionally, they don't harm the environment, animals, or people (One Health). By adding the aforementioned advantages of nanomaterials to novel formulations, the efficacy of adulticides, pupicides, larvicides, ovicides, and repellents can be raised. According to Sap-Iam et al. (2010), a nanoformulation is any formulation with components at nanometric sizes that is expected to release active chemicals or promote mosquito toxicity in a manner that has been previously developed for increased efficacy (Sap-Iam et al., 2010). Numerous kinds of nanomaterials with appropriate functions that contain both organic and inorganic components have been reported; these include formulations based on lipids, formulations based on organic polymers, nanoemulsions, nanosuspension, nanofibre, and inorganic metallic nanoparticles (Al-Samarrai, 2012).

Controlled release formulations allow for the precise and synchronized release of active substances to their target locations. Their large surface area and exceptional sensitivity to environmental conditions make them the ideal delivery vehicle. Several nanostructures and nanoencapsulations employed in mosquito control are studied for their physicochemical characteristics (Mandodan et al., 2023).

Effectiveness Compared to Traditional Methods: Vector control methods based on nanotechnology have shown to be more sustainable and effective than conventional chemical treatments. They provide a precise, targeted method that minimizes environmental harm and vector resistance by reducing the need for extensive pesticide application (Punniyakotti et al., 2024).

Nanomedicine in Disease Diagnosis and Treatment

By offering cutting-edge instruments for the diagnosis and treatment of vector-borne illnesses, nanomedicine is revolutionizing veterinary medicine. Diseases including anaplasmosis, babesiosis, and theileriosis must be controlled by early detection and efficient treatment. Targeted medicine delivery and extremely sensitive diagnostic testing are made possible by nanotechnology, which increases therapeutic effectiveness while reducing adverse effects.

Nano-Diagnostics for Early and Accurate Disease Detection

Blood smears, serological testing, and PCR-based approaches are the mainstays of traditional vector-borne illness diagnostics. But these techniques can be expensive, time-consuming, and may call for certain tools. By creating nano-based sensors and diagnostic platforms, nanomedicine offers the chance to improve diagnostic speed and accuracy (Singh et al., 2022). Magnetic, semiconductor, polymeric, and metallic nanoparticles have all been employed in designing nanostructures for disease diagnostics. The ability of nanoparticles to have their surfaces altered by polymers, antibodies, or aptamers extends their half-life and reduces the risk of toxicity, even if their unique optical, magnetic, and size-dependent properties make them promising candidates for disease diagnosis.

By conjugating these nanoparticles with aptamers, sensitive, highly selective, reusable, and label-free sensors with fluorescent, optical, and electrochemical detection signals have been created. Nanostructures have improved medical diagnosis by providing low-cost, reproducible, sensitive, and highly specific disease diagnosis methods through the use of sensors or imaging agents (Bansal et al., 2020). For example, gold nanoparticles have been used to create colorimetric tests that enable the rapid detection of vector born diseases like *Babesia* and *Theileria spp.* in blood samples (Tubalinal et al., 2021). Additionally, early diagnosis is made feasible by nano diagnostic technology, which is crucial for stopping the spread of infection and lessening the overall effect on animal papulations. In an attempt to potentially transform the disease surveillance, researchers are examining the direct detection of disease-related molecular markers from animal samples using quantum dots, nano sensors and biosensors (Wang et al., 2017).

Targeted Drug Delivery in Treatment

The drawbacks of conventional therapeutic methods include nonspecificity, limited bioavailability, poor solubility, and short circulation half-life. Due to all of these considerations, substantial dosages of therapeutic medications are required, which might result in cytotoxicity and other systemic side effects (Bansal et al., 2020). The capacity of nanomedicine to precisely transport the medication to the infection site, increasing therapeutic efficacy, is one of its main benefits. The effectiveness of treatment for vector-borne diseases can be increased by encapsulating and releasing drugs in a regulated manner using nanoparticles like liposomes and dendrimers (Chenthamara et al., 2019).

For instance, to guarantee that the medication is concentrated at the site of infection and reduce systemic toxicity, anti-babesia can be directly injected utilizing nanoparticles into erythrocytes infected with *Babesia* parasites (Couto et al., 2021). Additionally, using nanomaterials to deliver medications lessens side effects by enabling the administration of lower amounts (Chenthamara et al., 2020).

Examples of Nanomedicine Applications in Treating Vector-Borne Diseases

Numerous vector-borne illnesses are being effectively treated with nanomedicines. Studies on babesia infections have demonstrated that by more precisely targeting the parasites, a nanoparticle-based delivery system can increase the effectiveness of anti-babesia medications (Pandian et al., 2021). Additionally, nanotechnology has demonstrated the potential to cure and control *Anaplasma* infections by guaranteeing the bioavailability of medications and enhancing their stability (Kumar et al., 2024).

Nanovaccines: Prevention of Vector-Borne Diseases

Nanovaccines, which employ nanotechnology to improve vaccine administration and efficacy, provide a number of advantages over traditional vaccines. A promising strategy for preventing viral and non-communicable illnesses is the use of mucosal nanovaccines. Recent years have seen the successful usage of nanoparticles in immunization due to their unique properties. When employed as antigen transporters, many of these materials have a positive effect on vaccine effectiveness. Mucosal vaccines are the most practical immunization strategy because they are easy to administer (improving patient comfort and compliance), allow for the elicitation of relevant immune responses both at the site of administration and in distant compartments, and may therefore protect the main pathogen entry portal (oral, nasal, and genital mucosae) (Rosales-Mendoza et al., 2019).

Nanotechnology in Vaccine Development

Vaccines that are easier to administer, more stable, and have a longer shelf life can be developed thanks to nanotechnology. Antigens can be encapsulated by nanoparticles, guaranteeing a regulated delivery to the immune system. This strengthens the immune system and may lessen the need for booster doses (Peek et al., 2008). Additionally, by targeting certain elements of vector-borne diseases, such the surface proteins of parasites like *Babesia* or *Anaplasma*, nanovaccines can strengthen the immune system and offer long-term protection (Kumar et al., 2024).

Nanovaccines have the potential to enhance immunological memory, boost and accelerate immune responses, and enhance antigen presentation (Pandian et al., 2021).

Safety Concerns and Toxicity Issues

The possible toxicity of nanoparticles is one of the main issues with using nanomedicine on animals. Nanoparticles can readily interact with biological systems due to their small size, which may have negative consequences. Nanoparticles due of their small size can build up in organs including liver, spleen, and kidneys and contribute to long term damage (Ali et al., 2021).

Ethical Considerations

It's important to think about the moral ramifications of employing nanotechnology on animals. Thorough research and ethical guidelines are required to address worries about animal welfare, possible injury, and the wider environmental implications of nanoparticles (Coles & Frewer, 2013). The long-term impacts of nanomedicines on ecosystems and wildlife are also debatable.

Future Prospects and Challenges

Because of its novel approach to treating vector-borne diseases, nanomedicine has enormous potential for the future of veterinary research. However, before nanomedicine is widely adopted, a number of issues need to be resolved. Notwithstanding the possible advantages, a number of issues keep the nanomedicine from being applied more frequently in veterinary care. Ethical concerns including public acceptance, strict regulations, and costly development costs limit the potential of nanomedicine. Furthermore, because nanomaterials' extensive use may have unforeseen implications, their environmental impact requires careful investigation (Jahanmahin & Borji, 2023). Personalized medicine, in which treatment plans are customized for specific animals based on their genetic profiles, is one of the most intriguing uses of nanomedicine that researchers are currently investigating. Additionally, there is rising interest in using nanomaterials to create real-time diagnostic systems and intelligent vaccines that might completely transform veterinary care (El-Sayed & Kamel, 2022).

Conclusion

Although there is a lot of advancement in disease diagnosis and its therapeutic management but there are many challenges for veterinary care including vector born diseases that cause significant economic losses globally every year. The development of nanovaccines, target drug delivery systems, and rapid and improved diagnostic tools are some of the innovative approaches of nanomedicine that are ensuring the timely diagnosis, treatment, and prevention from vector-borne diseases. Because of its novel approach and nanoscale materials, nanotechnology is used in detection, control, prevention and management of the vector born diseases. The most important factors that drive the application of nanoscale materials in the creation of nanovaccines are their expended diffusion capacity, improved immunity and stability. The main concerns associated with nanomedicine are safety, regulation, and public acceptance. As more research and studies are carried out, nanomedicine has the potential to play a significant role in managing veterinary diseases, ensuring healthier animals and more environmentally friendly farming practices.

References

Abdela, N., & Bekele, T. (2016). Bovine theileriosis and its control: a review. *Advances in Biological Research*, *10*(4), 200-212.

Abdollahdokht, D., Gao, Y., Faramarz, S., Poustforoosh, A., Abbasi, M., Asadikaram, G., & Nematollahi, M. H. (2022). Conventional agrochemicals towards nano-biopesticides: an overview on recent advances. *Chemical and Biological Technologies in Agriculture*, *9*(1), 13.

Ali, A., Ijaz, M., Khan, Y. R., Sajid, H. A., Hussain, K., Rabbani, A. H., & Ahmed, I. (2021). Role of nanotechnology in animal production and veterinary medicine. *Tropical Animal Health and Production*, *53*, 1-14.

Al-Samarrai, A. M. (2012). Nanoparticles as alternative to pesticides in management plant diseases-a review. *International Journal of Scientific and Research Publications*, *2*(4), 1-4.

Appenzeller, T. (1991). The Man Who Dared to Think Small: In a visionary lecture 32 years ago, Richard Feynman predicted many of the advances that are the subject of this special section of Science—and foresaw their implications. *Science*, *254*(5036), 1300-1300.

Aubry, P., & Geale, D. W. (2011). A review of bovine anaplasmosis. *Transboundary and Emerging Diseases*, *58*(1), 1-30.

Auría-Soro, C., Nesma, T., Juanes-Velasco, P., Landeira-Viñuela, A., Fidalgo-Gomez, H., Acebes-Fernandez, V., & Fuentes, M. (2019). Interactions of nanoparticles and biosystems: microenvironment of nanoparticles and biomolecules in nanomedicine. *Nanomaterials*, *9*(10), 1365.

Baker, J. R., Quintana, A., Piehler, L., Banazak-Holl, M., Tomalia, D., & Raczka, E. (2001). The synthesis and testing of anti-cancer therapeutic nanodevices. *Biomedical Microdevices*, *3*, 61-69.

Bakker-Woudenberg, I. A., Schiffelers, R. M., Storm, G., Becker, M. J., & Guo, L. (2005). Long-circulating sterically stabilized liposomes in the treatment of infections. In *Methods in enzymology* (Vol. 391, pp. 228-260). Academic Press.

Bansal, M., Kumar, A., Malinee, M., & Sharma, T. K. (2020). Nanomedicine: Diagnosis, treatment, and potential prospects. *Nanoscience in Medicine, 1*, 297-331.

Basu, P., & Bhattacharya, S. (2021). Nanotechnology and polymer science: a novel approach in vector control. *Genetically Modified and other Innovative Vector Control Technologies: Eco-bio-social Considerations for Safe Application*, 347-358.

Bhatnagar, C. S., Bhardawaj, B., Sharma, D. K., & Meena, S. K. (2015). Incidence of haemoprotozoan diseases in cattle in Southern Rajasthan, India. *International Journal of Current Microbiology and Applied Sciences*, *4*(3), 509-514.

Bibi, S., Abbas, S., Zaman, M. A., Gul, R., Batool, A. I., Bowman, D., & Naheed, T. (2024). Effectiveness of Nanoparticles to Control Ticks and Tick-borne Diseases. Effectiveness of nanoparticles to control ticks and tick-borne diseases. In: Ahmed R, Khan A, Abbas RZ, Farooqi SH and Asrar R (eds), *Complementary and Alternative Medicine: Nanotechnology-II*, (pp. 356-363). Unique Scientific Publishers, Faisalabad, Pakistan.

Boozer, A. L., & Macintire, D. K. (2003). Canine babesiosis. *Veterinary Clinics: Small Animal Practice*, *33*(4), 885-904.

Chauhan, R. S., Sharma, G., & Rana, J. M. S. (2010). Nanotechnology in health and disease. *Bytes and Bytes, Bareilly, UP, India*, 1-11.

Chenthamara, D., Subramaniam, S., Ramakrishnan, S. G., Krishnaswamy, S., Essa, M. M., Lin, F. H., & Qoronfleh, M. W. (2019). Therapeutic efficacy of nanoparticles and routes of administration. *Biomaterials Research*, *23*(1), 20.

Chenthamara, D., Subramaniam, S., Ramakrishnan, S. G., Krishnaswamy, S., Essa, M. M., Lin, F. H., & Qoronfleh, M. W. (2019). Therapeutic efficacy of nanoparticles and routes of administration. *Biomaterials Research*, *23*(1), 20.

Coles, D., & Frewer, L. J. (2013). Nanotechnology applied to European food production–A review of ethical and regulatory issues. *Trends in Food Science & Technology*, *34*(1), 32-43.

Couto, J. M. G. T. (2021). *Vector-pathogen interactomics: connecting the dots* (Doctoral dissertation, Universidade NOVA de Lisboa (Portugal)).

Dantas-Torres, F., & Otranto, D. (2016). Best practices for preventing vector-borne diseases in dogs and humans. *Trends in Parasitology*, *32*(1), 43-55.

Day, M. J. (2011). One health: the importance of companion animal vector-borne diseases. *Parasites & Vectors*, *4*, 1-6.

De, A., Bose, R., Kumar, A., & Mozumdar, S. (2014). *Targeted delivery of pesticides using biodegradable polymeric nanoparticles* (Vol. 10, pp. 978-81). New Delhi: Springer India.

Dey, A., Biswal, S., & Sundarapandian, S. (2022). Nanotechnology applications in nanomedicine: prospects and challenges. *Diverse Applications of Nanotechnology in the Biological Sciences*, 1-37.

El-Sayed, A., & Kamel, M. (2020). Advanced applications of nanotechnology in veterinary medicine. *Environmental Science and Pollution Research*, *27*, 19073-19086.

Feneque, J. (2003). Brief introduction to the veterinary applications of nanotechnology. *Nanotechnology Now. On line: http://www. nanotech–now. com/Jose–Feneque/Veteri–nary–Applications–Nanotechnology. htm.*

Garcia, K., Weakley, M., Do, T., & Mir, S. (2022). Current and future molecular diagnostics of tick-borne diseases in cattle. *Veterinary Sciences*, *9*(5), 241.

Garros, C., Bouyer, J., Takken, W., & Smallegange, R. C. (2018). 20. Control of vector-borne diseases in the livestock industry: new opportunities and challenges. *Pests and Vector-Borne Diseases in the Livestock Industry*, 575-580.

Getahun, M. N., Villinger, J., Bargul, J. L., Muema, J. M., Orone, A., Ngiela, J., & Masiga, D. K. (2022). Molecular characterization of pathogenic African trypanosomes in biting flies and camels in surra-endemic areas outside the tsetse fly belt in Kenya. *International Journal of Tropical Insect Science*, *42*(6), 3729-3745.

Ghormade, V., Deshpande, M. V., & Paknikar, K. M. (2011). Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnology Advances*, *29*(6), 792-803.

Hazra, S., & Patra, S. (2023). Carbon Nanomaterials in Biosensor Applications for Infectious Disease Diagnostics. In *Carbon Nanostructures in Biomedical Applications* (pp. 257-283). Cham: Springer International Publishing.

Irwin, P. J. (2009). Canine babesiosis: from molecular taxonomy to control. *Parasites & Vectors*, *2*(Suppl 1), S4.

Jahanmahin, A., & Borji, H. (2023). Nanotechnology-based Approaches for the Treatment of Toxocariasis: A Prospective Review. *Journal of Veterinary Physiology and Pathology*, *2*(2), 12-19.

Jain, K. K. (2005). Nanotechnology in clinical laboratory diagnostics. *Clinica Chimica Acta*, *358*(1-2), 37-54.

Kasozi, K. I., Matovu, E., Tayebwa, D. S., Natuhwera, J., Mugezi, I., & Mahero, M. (2014). Epidemiology of increasing hemo-parasite burden in Ugandan cattle. *Open Journal of Veterinary Medicine*, *4*(10), 220-231.

Kim, J. E., Shin, J. Y., & Cho, M. H. (2012). Magnetic nanoparticles: an update of application for drug delivery and possible toxic effects. *Archives of Toxicology*, *86*(5), 685-700.

Kiruthika, A., & Bhattacharya, A. (2024). Nano-revolution in Vector-Borne disease management: Exploring control strategies and mechanisms. *International Journal of Entomology Research*, 9(4), 175-178. ISSN: 2455-4758

Kroubi, M., Daulouede, S., Karembe, H., Jallouli, Y., Howsam, M., Mossalayi, D., & Betbeder, D. (2010). Development of a nanoparticulate formulation of diminazene to treat African trypanosomiasis. *Nanotechnology*, *21*(50), 505102.

Kumar, R., Malik, H. N., Mohapatra, S. K., Kumari, K., Chowdhury, A., & Ghosh, M. (2024). Nanointerventions in the Treatment of Protozoan Livestock Diseases. In *Nanotechnology Theranostics in Livestock Diseases and Management* (pp. 483-513). Singapore: Springer Nature Singapore.

Liang, J., Yao, L., Liu, Z., Chen, Y., Lin, Y., & Tian, T. (2024). Nanoparticles in Subunit Vaccines: Immunological Foundations, Categories, and Applications. *Small*, 2407649.

Little, S. E. (2008). Vector-borne diseases. *Georgis' Parasitology for Veterinarians-E-Book*, 240.

Mandodan, S., Kunnikuruvan, A., Bora, B., Padmanaban, H., Vijayakumar, A., Gangmei, K., & Poopathi, S. (2023). Applications of nanomaterials in mosquito vector control: a review. *Asian Pacific Journal of Tropical Medicine*, *16*(11), 479-489.

Mishra, B. B. T. S., Patel, B. B., & Tiwari, S. (2010). Colloidal nanocarriers: a review on formulation technology, types and applications toward targeted drug delivery. *Nanomedicine: Nanotechnology, Biology and Medicine*, *6*(1), 9-24.

Mishra, P., Tyagi, B. K., Chandrasekaran, N., & Mukherjee, A. (2018). Biological nanopesticides: a greener approach towards the mosquito vector control. *Environmental Science and Pollution Research*, *25*, 10151-10163.

Mody, V. V., Siwale, R., Singh, A., & Mody, H. R. (2010). Introduction to metallic nanoparticles. *Journal of Pharmacy and Bioallied Sciences*, *2*(4), 282-289.

Mohantya, N., Palaib, T., Prustyc, B., & Mohapatrad, J. (2014). An overview of nanomedicine in veterinary science. *Veterinary Research*, *2*(4), 90-5.

Muller, R. H., & Keck, C. M. (2004). Challenges and solutions for the delivery of biotech drugs–a review of drug nanocrystal technology and lipid nanoparticles. *Journal of Biotechnology*, *113*(1-3), 151-170.

Nagar, B. Nano-revolution in Vector-Borne disease management: Exploring control strategies and mechanisms. (2024). Exploring control strategies and mechanisms. *International Journal of Entomology Research, 9*(4). 175-178.

Nordly, P., Madsen, H. B., Nielsen, H. M., & Foged, C. (2009). Status and future prospects of lipid-based particulate delivery systems as vaccine adjuvants and their combination with immunostimulators. *Expert Opinion on Drug Delivery*, *6*(7), 657-672.

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

Peek, L. J., Middaugh, C. R., & Berkland, C. (2008). Nanotechnology in vaccine delivery. *Advanced Drug Delivery Reviews*, *60*(8), 915-928.

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 & Agroforestry*, *4*, 28-60.

Punniyakotti, P., Vinayagam, S., Rajamohan, R., Priya, S. D., Moovendhan, M., & Sundaram, T. (2024). Environmental Fate and Ecotoxicological Behaviour of Pesticides and Insecticides in Non-Target Environments: Nanotechnology-Based Mitigation Strategies. *Journal of*

Environmental Chemical Engineering, *12*(5), 113349. https://doi.org/10.1016/j.jece.2024.113349

Rosales-Mendoza, S., & González-Ortega, O. (2019). *Nanovaccines*. Springer International Publishing. Pp 343. https://doi.org/10.1007/978-3-030-31668-6.

Sap-Iam, N., Homklinchan, C., Larpudomlert, R., Warisnoicharoen, W., Sereemaspun, A., & Dubas, S. T. (2010). UV irradiation-induced silver nanoparticles as mosquito larvicides. *Journal of Applied Sciences, 10*(23), 3132-3136. http://scialert.net/qredirect.php?doi=jas.2010.3132.3136&linkid=pdf

Sarode, R. J., & Mahajan, H. S. (2024). Dendrimers for Drug Delivery: An Overview of its Classes, Synthesis, and Applications. *Journal of Drug Delivery Science and Technology*, 105896.

Silaghi, C., Santos, A. S., Gomes, J., Christova, I., Matei, I. A., Walder, G., & Dumler, J. S. (2017). Guidelines for the direct detection of Anaplasma spp. in diagnosis and epidemiological studies. *Vector-Borne and Zoonotic Diseases*, *17*(1), 12-22.

Singh, D., Patel, P., & Soni, R. (2022). Nanodiagnostics in veterinary medicine: Advances and challenges. *Veterinary Journal, 34*(1), 15-23. https://doi.org/10.1016/j.tvjl.2022.01.007

Solano-Gallego, L., & Baneth, G. (2011). Babesiosis in dogs and cats—expanding parasitological and clinical spectra. *Veterinary Parasitology*, *181*(1), 48-60.

Tilahun, A. N. B. (2016). Epidemiology and Control of Bovine Theileriosis in Ethiopia. *Epidemiology*, *23*. 32-44

Tubalinal, G. A. S., Lucero, L. P. G., Mangahas, J. A. V., Villanueva, M. A., & Mingala, C. N. (2021). Application of Noble Metals in the Advances in Animal Disease Diagnostics. In *Updates on Veterinary Anatomy and Physiology*. IntechOpen. DOI:10.5772/intechopen.99162. https://www.intechopen.com/chapters/78018

Underwood, C., & Van Eps, A. W. (2012). Nanomedicine and veterinary science: The reality and the practicality. *The Veterinary Journal*, *193*(1), 12-23.

Vishwakarma, P., & Nandini, M. K. (2019). Overview of canine babesiosis. *Veterinary Medicine and Pharmaceuticals*, 109.

Wang, Y., Yu, L., Kong, X., & Sun, L. (2017). Application of nanodiagnostics in point-of-care tests for infectious diseases. *International Journal of Nanomedicine*, 4789-4803.

Wilson, A. J., Morgan, E. R., Booth, M., Norman, R., Perkins, S. E., Hauffe, H. C., & Fenton, A. (2017). What is a vector?. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1719), 20160085.

Yang, L., & Alexandridis, P. (2000). Physicochemical aspects of drug delivery and release from polymer-based colloids. *Current Opinion in Colloid & Interface Science*, *5*(1-2), 132-143.