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Emerging roles of nanotechnology in veterinary medicine: Targeted therapy and disease control

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ABSTRACT

A game-changing tool in veterinary medicine is nanotechnology, which is the modification of material at the nano-scale (1-10nm). This technology is used in the field of medicine as a nanomedicine that can be applied to create effective vaccines, disease diagnosis and prevention, targeted drug delivery, and prevent drug resistance in animals. Nanoparticles like metallic, polymeric, liposomes, and exosomes improve the solubility, bioavailability of the drugs, and their therapeutic effect by reducing the dosage and effectiveness of the drugs. Infectious diseases like FMD, MRSA, and inflammatory bowel disease can all be well-treated with the precise distribution of the drug to the targeted site. In addition, the NPs act as carriers for the vaccines to improve and boost the immune response. Some obstacles, such as biological hurdles, precise delivery, regulatory complications, and financial limitations, that we have to face. Overall, nanotechnology holds a promising future in animal health, offering new approaches for the diagnosis, treatment, and management of diseases.

Keywords: Nanotechnology, Veterinary Nanomedicine, Nanoparticles in Animal Health

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Introduction

The term "nanotechnology" was initially used in 1974 to refer to scientific instruments used for nanoscale material manipulation. Materials that have one or more of their three dimensions measuring between 1 and 100 nm are typically referred to as nanoscale materials. DNA, which has a width of 2.5 nm, and protein molecules, which have an average width of 5 nm, are examples of naturally occurring nanoscale biological materials [1]. Nanotechnology is a cutting-edge scientific field that has created the way for creative and inventive methods in several medical science fields. The National Science and Technology Council of the United States (2004) described nanotechnology as a field that deals with the observation, evaluation, and manipulation of matter at the atomic, molecular, and supramolecular levels. Human and animal health, drug delivery, poor drug efficacy, poor drug distribution, environmental dangers, and safety-derived animal yields are the main issues that are anticipated to move from biotechnology to creative nanotechnology [2]. Nowadays, the term "nanobiotechnology" is used to refer to the application of nanotechnology in medical science. Nanomedicine is used to create quicker and more effective solutions for biological issues or disease management. Conventional medications, however, have significant adverse effects and are useless as treatments for inflammatory illnesses, such as inflammatory bowel disease (IBD). Additionally, several inflammatory disorders, such as stroke, which is the world's leading cause of death and disability, still lack safe and effective therapeutic medications. In addition to overcoming the obstacles that conventional medicine faces (like drug resistance, poor efficacy, and poor drug distribution to target sites), it makes it possible to comprehend a variety of physiological and pathological processes [3]. There are other terms used as well, like nanotheranostics. These are novel formulations that can be used for both therapeutic and diagnostic purposes. Infections, which are frequently caused by bacteria, fungi, viruses, parasites, and other microbes, pose a major threat to the health of animals. In this section, the therapies against infectious diseases include the development of the nanomedicine platform, vehicles for the drug delivery, drugs with direct anti-inflammatory action, vaccine development, diagnostic methods, and prevention of drug resistance. The application of nanomedicine gives us information on the targeted site of the drug, the site of release, and its effectiveness [4].

Fundamentals of Nanotechnology in Veterinary Medicine

Nanomedicine is a vast field of technology and medicine that deals with the study of various applications like disease prevention and management, targeted site of drug delivery, animal health improvement, and pain and traumatic injury management [5]. According to this phenomenon, NPs can be employed in the reformulation of conventional medications to improve their pharmacokinetics, decrease their immunotoxicity, and raise their solubility. Nano-techniques can be used to improve the bioavailability of pre-existing drugs, hence boosting their efficacy, targeted distribution, reducing systemic side effects, and limiting dosages. They can also be used as carriers. They can also be used as a vehicle. For veterinary health issues, nanotechnology offers strong solutions. It has high therapeutic potential for animal health issues. NPs can be used to eradicate animal infectious pathogens like blood, intercellular parasites, and acute and chronic infections. NPs can be categorized in a variety of ways according to the (1) origin of their nanomaterials. NPs fall into one of four categories: (1) organic (such as peptides, amino acids, or lipids); (2) inorganic (such as the metals gold, silver, silica, magnesium, iron, or grapheme); (3) hybrid (such as sphere-shaped, the tubes, or liquid drops); and (4) usage and payload type (such as nutrition, medicine, diagnostics, or vaccine administration) [6].

Targeted Drug Delivery in Animals

Targeted drug delivery in nanotechnology involves NPs prepared in such a way that helps to transport and deliver the medication precisely to the target site of action. A big evolution in the field of drug delivery is brought by the development of nanomedicine that provides an effective and targeted delivery of drugs, minimizing the side effects, reducing drug resistance, and effectiveness of the drugs. NPs are used for immunotherapy, infectious disease treatment, diagnosis, prevention, and other applications. Their use as adjuvants and vaccine means of distribution can improve antigen immunogenicity and targeted immune responses generated by immunization. Meanwhile, nanomaterials, including lipid nanoparticles (LNPs), liposomes, exosomes, and polymeric nanoparticles, can be used as delivery systems for effective treatment, targeted drug distribution, and controlled release [8]. By adjusting their surface functional groups, nanomaterials such as magnetic nanoparticles (NPs) and quantum dots (QDs) may be used in biomedical imaging to monitor the course of diseases in real time and identify specific targets with great sensitivity [9].

Some advantages of using nanotechnology in medicine distribution include the following: First of all, it enables targeted and controlled drug delivery to specific body sites, such as tumors, inflammatory tissue, and polluted regions. As a result, fewer side effects and less medicine are needed. Second, medications can be made more stable and soluble by nanoparticles, which increases their efficacy in curing illnesses. Thirdly, by improving the medications' absorption and distribution inside the body, nanotechnology

can raise their bioavailability. This reduces toxicity by enabling the use of lower dosages of medications [10].

- There are two types of polymeric nanoparticles (NPs): (1) synthetic polymers like polyethylene glycol (PEG) and (2) natural polymers made from polysaccharides like chitosan and inulin. They are distinguished by their powerful loading/conjugating ability.
- Liposomes are spherical, biodegradable, PEGylated nanoparticles that are non-toxic. They carry RNA, DNA, radionuclides, water-soluble drugs, or siRNA (small-interference RNA) for therapeutic purposes in their aqueous core.
- Metallic nanomaterials: These can be made from a variety of metals, primarily gold. Their primary application is in the management of cancer.
- Stabilized lipids in aqueous solutions make up solid lipid nanoparticles. They dissolve drugs based on lipophilic radioactive materials (for cancer therapy) thanks to their hydrophobic lipid core.

Role in Disease Control and Prevention:

Animal health is seriously threatened by infections, which are commonly brought on by bacteria, fungi, viruses, parasites, and other microorganisms. The invention of nanomedicine platforms, nanocarrier delivery systems, medications with direct anti-infective properties, and infectious disease diagnostic techniques was among the treatments for infectious diseases covered in this section [11]. Nanotechnology offers revolutionary solutions for the most important problems veterinarians deal with, such as leptospirosis, methicillin-resistant Staphylococcus aureus (MRSA), foot-and-mouth disease (FMD), TB, and even diseases with cellular or blood pathogens. They also developed NPs that target the toxins of bacteria and receptors to bind the harmful microbiota in the stomach before they are eliminated from the body. NPs were also used for various diagnostic purposes, such as a contrast agent for MRI in cats. When treating canine prostatic cancer, gold nanoparticles (NPs) took the place of surgical intervention. The dosages needed for the employed treatment protocol are a thousand times lower than those of chemotherapy, and it has no adverse effects on healthy tissues [12]. The use of NPs in the production of veterinary vaccines is growing. They enhance the immune responses through basic immunomodulatory processes. They activate the cells that display antigens and enhance the cross-presentation of peptides. Additionally, they can function as adjuncts to lessen the antigen's release, improving the vaccine's effectiveness. Additionally, the antigen-loaded NPs may target the lymph nodes directly, increasing the effectiveness of the vaccine [13].

Challenges, Limitations, and Future Perspectives

Many studies in the last few years have concentrated on the creation and application of nano-formulations as treatment strategies for inflammatory and infectious disorders. Although nanomedicine has several benefits over traditional drugs in veterinary medicine that cannot be matched, there are also many drawbacks and difficulties that need to be resolved. The creation of nano-formulations continues to face a number of difficulties. One is the difficulty of delivering medications through various biological barriers. Certain NPs drug delivery systems may encounter biological obstacles in systems including the gastrointestinal tract and lung, which can hinder their transit and make targeted aggregation challenging. The second is the difficulty of prescribing, characterizing, and preparing NPs. Third, there are issues with regulations and costs. The amount of time and money required to bring nanomedicines to market is immeasurable, and one of the biggest obstacles is regulatory concerns. To ensure quality, safety, and efficacy, nanomedicines must be progressively compared to reference medications [14].

Conclusion

In the veterinary industry, nanomaterials can fundamentally alter how diseases are detected, managed, and avoided. The process of modifying material at such a small scale that it is possible to accurately regulate their structural, chemical-based, and physiological properties, which differ significantly from those of their bulk counterparts, is known as nanotechnology. This opens up new opportunities for the development of targeted drug delivery systems, sensitive diagnostic tools, and novel treatments. Additionally, nanotechnology can have direct anti-inflammatory and anti-pathogenic effects. Nanotechnology is expected to become a necessity in the veterinary field rather than a choice in the near future. The main necessity is to reduce the dangers and toxicological issues associated with the excessive use of nanomaterials in veterinary medicine and treatment regimens, and with high doses. All things considered, nanotechnology has a bright future in veterinary healthcare and medicine, with the potential to transform how we prevent and cure illness and improve patient outcomes.

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