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Review Article

A review on nanotechnology and its application in modern veterinary science

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Abstract

The term nanotechnology refers to material processing on the atomic or molecular scale, especially for the construction of microscopic level devices with the ability to calculate, function, and organize. The microscopic level typically refers to the size range of 1–100 nm. We opt to review the application of nanotechnology in veterinary medicine for this specific article and highlight their functions in animal health and production improvement. Nanotechnology plays a key role in veterinary medicine and other areas of animal production and also plays a significant role in the treatment of diseases through the development of a system for the delivery of smart medicines. Nanotechnology has revolutionized virtually all veterinary medicine and animal science disciplines these days by offering new, small-scale devices and materials that are beneficial to living organisms. Nanoparticles used for disease detection, treatment, delivery of medications, animal breeding, and reproduction include quantum dots, magnetic nanoparticles, nanopores, polymeric nanoparticles, nanoshells, fullerenes, liposomes, and dendrimers. While nanotechnology is regarded as one of the foremost technologies already applied in diverse subjects, its application in veterinary science is still in its infancy stages when compared to other sister disciplines.

Introduction

The term nanotechnology refers to the nanoscale-level ability to calculate, function, and organize the matter. The scale usually refers to the matter in the size range of 1–100nm in at least one dimension but is often extended to include materials in size below 1nm [1,2]. It is not limited to a specific sector; rather, it is an enabling collection of technologies, which cross all sectors of activity and scientific disciplines. Nanotechnology uses the philosophy and techniques of the nanoscale to understand and transform biosystems, which use biological concepts and materials to build new nanoscale devices and systems [3,4].

Rationally engineered nanostructures are among the most impressive man-made materials and unveil distinctive chemical, physical, and/or biological characteristics [5]. Such characteristics make it possible to use the nanostructures for an exceptional number of applications in various sectors including electronics, agriculture, and health care [6].

One of the key benefits of nanotechnology is to close the gap between the worlds of macroscopy and microscopy, where nanoparticles are the perfect medium to communicate with biological systems [7]. Nanoparticles have different properties that differentiate them from bulk materials that include large active surfaces, easily controllable surface chemistry that allows binding to small molecular drugs, imaging labels, and ligands such as antibodies, peptides, nucleic acids. Also, their small size allows for exclusive intracellular and extracellular interactions, such as extravasation via endothelial cells and increased permeability and retention in tumor tissues [8-10].

It is believed that nanotechnology will deliver a large number of breakthroughs in the twenty-first century that will advance the habit of clinical veterinary medicine and have the ability to modernize veterinary medicine, animal welfare and other areas of animal production [11]. Veterinary nanotechnology will enhance the systems of diagnosis and treatment delivery, provide new gears for molecular and cellular breeding, animal history from birth to consumer table, animal nutrition scenarios ranging from nutrient uptake, and use, animal waste adjustment as expelled from livestock, pathogen detection, and much more [12]. In this paper, we opt to review the application of nanotechnology in veterinary medicine and highlight their roles on animal health and production improvement.

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Classifications of nanoparticles

Nanoparticles are scale-sized microscopic particles of 1nm to 100nm [1,2,13]. Particles such as nanocrystals, polymers, dendrimers, silica oxides, carbon, metal oxides, lipids, and quantum dots have been developed over the last few decades on based on various components, along with an increasing variety of newly developed materials [14]. Some of the widely used nanoparticles were addressed below.

Fullerenes

Fullerenes are nanoparticles that consist entirely of molecules formed from carbon. Their nanomedicine capabilities are extensively studied, and their use in the manufacturing sector has already been established [15]. Carbon nanoparticles combine a broad variety of characteristics that can be useful in therapy, and regenerative medicine, including high aspect ratio, thermal, conductive and mechanical properties. One of the most commonly used nanotechnology fullerenes is Carbon Nanotubes (CNTs), which may be single or multi-walled (SW, MW). SWCNTs provide a new approach to the delivery of drugs because of their ability to reach cells in a 'needle-like' manner [16] and by diminishing their length they can gain nuclear exposure. This phenomenon is extremely useful since CNTs can be conjugated or charged with drugs to improve therapeutic effectiveness [16,17].

Quantum dots

Quantum dots are nanocrystals that measure between 2-10nm and can fluorescence when excited by light [18]. Their composition consists of an inorganic center, whose size defines the color of an inorganic shell emitted and an aqueous organic coating to which biomolecules are combined. It can be used as a diagnostic as well as a clinical method for biomedical purposes and can also be used for the imaging of sentinel nodes in patients with cancer to stage tumors and to scheme therapy [19].

Liposomes

Liposomes are synthetic vesicles of nanoscale size and a spherical form consisting of natural phospholipids and cholesterol [20]. Liposomes were the first to be tested as carriers of the drugs. They are micro-particular or colloidal carriers, typically with a size range of 80–300nm [21]. These can be used as effective systems for the administration of drugs. Cancer chemotherapeutic and other toxic medicines, such as amphotericin and hamycin, show greater efficacy and protection when used as liposomal medicines compared to traditional preparations [22].

Magnetic nanoparticles

Magnetic nanoparticles, such as iron oxide paramagnetic compounds are promising candidates for disease treatment due to the ability of antibodies to bind to their surface and the possibility of targeting using an external magnetic field [13]. The most capable substances tend to be superparamagnetic iron oxide nanoparticles of less than 10nm in diameter and with superior magnetic properties. They are small, thermally agitatedw magnets called "ferromagnetic fluids" or "ferrofluids" in liquids. Superparamagnetism only occurs through the presence of a magnetic field; if this is removed, the magnetization will vanish, particles will cease to interact, and thus potential vascular embolization can be avoided [13,23].

Nanopores

Nanopores were conceived by Desai and Ferrari in 1997 [24]. Consists of high porous density wafers reaching up to 20nm in diameter. The pores allow for the flow of oxygen, glucose, and other items, such as insulin. This does not require immunoglobulins and cells to move through them, though. Nanopores can be used as a tool to protect grafted tissues from the host defense system. β pancreatic cells may be enfolded inside the nanopore system and inserted in the body of the recipient. This tissue sample absorbs the nutrients from the nearby tissues while remaining invisible by the defense system and hence escapes from rejection. It can serve as a newer treatment tool for insulin-dependent diabetes mellitus [25].

Nanoshells

Nanoshells had been produced in West and Halas [26]. Nanoshells consist of silica nucleus nanoparticles, and a thin metal layer covering. This can be applied to appropriate tissue using immunological methods. This technique is under analysis for tumor therapy. Used nanoshells that are designed to absorb infrared rays when bared from a source outside the body to exhibit the nanoshell's Thermo ablative property [27].

Applications of nanotechnology in veterinary science

Nanotechnology is used for the production of nanoscale drugs, controlled delivery systems, contaminant detection, and for the design of molecular and cellular biology nanodevices [28]. It will have a major role in animal welfare, veterinary medicine, and other animal production fields, and will also play an essential role in disease control through the implementation of a smart drug delivery system. One practical function of nanotechnology in medicine, which is currently being developed, involves the use of nanoparticles to administer drugs or other constituents to specific cell types. Particles are programmed to be drawn to diseased cells that cause certain cells to be handled directly [29]. Some of the veterinary science's major nanotechnological approaches have been reviewed below

Nanovaccines

The nanovaccine is emerging as a new solution to the vaccination technique. Nanovaccines can stimulate both humoral and cell-mediated immune response and are more effective than traditional vaccines. They have the promise of channeling the body's immune system to combat pathogens and avoid the spread of infections and diseases [30,31]. The current method of vaccination has changed from live and killed organisms practice to a much safer candidate for synthetics and recombinants. Such new candidates for vaccine alone are often poorly immunogenic and vulnerable to degradation and need an engineered adjuvant that enhances immunogenicity [32].

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Due to the un-adjustability of conventional adjuvants, the introduction of nanotechnology has brought about a series of novel antigen-carrying strategies. Such adjuvants based on nanoparticles can be designed for reduced dose frequency and a comfortable route of administration to induce a particular target immune response, for instance, the intranasal route to improve target mucosal immunity. This makes them particularly suitable for veterinary medicine where large numbers of animals will need to be handled at once, or where vaccination by traditional means is impractical due to comprehensive management systems or lack of accessibility [33].

Nanopharmacuetics

Pharmacology and nanophamaceuticals are at the forefront of what nanotechnology can develop in comparison to the other veterinary medicine field [34]. Considering the field of pharmacology, it is important to reiterate that nanotechnology enables the production of new drugs and the possibility of reworking traditional substances to achieve better results in efficacy [35]. The pharmacokinetics and therapeutic index of the medicines can be greatly enhanced by inserting medications onto nanoparticles by physical encapsulation, adsorption, or chemical conjugation, as opposed to the free product equivalents. Drug-charged nanoparticles that invade host cells by endocytosis and then release drug payloads to treat intracellular infections that are caused by microbes [36].

Drug delivery based on nanoparticles provides many benefits, such as enhancing drug-therapeutic efficacy and pharmacological properties. Several nano-drug delivery systems have shown the effectiveness of nanoparticles in enhancing pharmacokinetics, reducing unwanted side effects, and optimizing transmission to disease sites [37]. The required dosage of the drug is used in this procedure and side effects are greatly minimized, as the active agent is concentrated only in the morbid area. This highly targeted approach will reduce patients' costs and pain [38].

In turn, the use of nanoparticulate drug carriers will overcome many important drug delivery problems including enhancing drug solubility and safety, increasing the half-lives of medications in the blood, reducing adverse effects in non-target organs, and focusing medications at the location of the disease [39]. Drugs may be spread in a gel, encapsulated in a vesicle, dissolved in a hydrophobic nucleus, or bound to a nanoparticle sheet. Many drug delivery mechanisms based on nanoparticles, including liposomes, polymeric nanoparticles, dendrimers, ceramic-containing capsules, micelles, and others have been used to transport therapeutic agents for small molecules, peptides, and oligonucleotides [40].

Liposomes were the first to be investigated as carriers of the drugs, which are spherical vesicles consisting of phospholipids and steroid, bilayers, or certain surfactants which shape spontaneously as other lipids are distributed in aqueous media where liposomes may be formed [41]. Liposomes have been reported to enhance drug solubility and boost their pharmacokinetic properties, such as the therapeutic index of chemotherapeutic drugs, accelerated synthesis and reduction of adverse side effects, and an improvement in *in vitro* and *in vivo* anticancer behavior. The encapsulation process embeds a drug in liposomes. The release of a drug from liposomes depends on the structure of the liposome, the pH, the osmotic gradient, and the atmosphere surrounding it [42]. Liposomal associations with cells can be understood through adsorption, fusion, endocytosis, and transition of lipids. Liposomal forms, such as anticancer medications, neurotransmitters, antibiotics, and anti-inflammatory medicines, have several medication sources [43].

Molecule variety retains possible therapeutic interest from which dendrimers grab wide applicability in drug conveyance. Dendrimers possess several versatile divisions that contain voids where the drug molecules can be stuck physically [44]. This compact construction makes for fantastic encapsulation. In nanotechnology, their structure made a major impact in providing well-controlled practical building blocks. Through drug distribution and cancer treatment, they have a variety of uses. Dendrimers are successfully used in drug distribution as they convey a drug at a precise rate by chemical modulation either by adjustment of hydrolytic release conditions and selective outflow of drug molecules depending on their size or form [45]. High-load dendrimers have demonstrated rapid pharmacological reactions with enhanced effectiveness [46].

Equivalently, carbon nanotubes with better strength and steadiness can also serve as product carriers. Binding antibodies to carbon nanotubes with fluorescent or radiolabeling will achieve in cell specificities [47]. Nanotubes joining the cell may be directed by endocytosis or by cell membrane penetration. By integrating carboxylic or ammonium groups into their arrangement, carbon nanotubes can be made more soluble and can be used for the transport of proteins and other drug molecules. Indium-111 carbon nanotubes labeled radionuclides are being investigated for selective killing of cancer cells [48].

Animal breeding and reproduction

Nanotechnology has started to flourish in the reproductive and reproduction sectors [49]. The goals of such nanotechnology-based animal reproduction investigations are to characterize nanoscale features of gamete cells using atomic force microscopy and similar scanning microscopy techniques, build nano-bio sensors for physiological or altered detection of the reproductive status [50], develop chemical tactics for the production of metal nanoparticles for fertility control applications, develop nanodevices for secure cryopreservation of gametes and embryos [51] and develop sustained release systems of molecules, including hormones, vitamins, antibiotics, antioxidants, nucleic acids, among others [52].

Breeding management is a costly and time-consuming problem for dairy farmers and pig farmers. One approach being tested now is a nanotube inserted under the skin to provide real-time monitoring of changes in blood estradiol levels. The nanotubes are used as a means of tracking estrus in animals, as these tubes are capable of binding and detecting the estradiol antibody by near-infrared fluorescence at the time of estrus.

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This sensor's signal will be integrated as part of a central breeding monitoring and control system for actuation [53]. In addition, nanotechnology devices such as microfluidics, nanoparticles, bioanalytic nano-sensors, can to solve even more puzzles related to animal health, growth, reproduction, and disease prevention and treatment [54]. Microfluidic and nanofluidic [55] are modern methods to improve conventional *in vitro* fertilization procedures and the development of in vitro embryos [56]. Recent reports have shown the usefulness of microfluidics in insulating motile sperm without centrifugation [57].

Disease diagnostics

In veterinary medicine, diagnosing a disease may take days, weeks, or even months as in the case of chronic diseases without any clinical symptoms. Hence, an infection may have grown by that time with the need to kill the entire herd. Nanotechnology operates on the same scale as a virus or disease-infecting particle and therefore has the potential to be detected and eradicate very early. Hence, nanotechnology, for sensitive clinical diagnosis can be a successful tool [58]. In the one health thought, the use of nanotechnology instruments for the examination of animal diseases or as animal simulations for the diagnosis of human diseases is remarkable. Latest studies propose the use of quantum dots in small animal models for *in vivo* imaging [4].

Single-Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) are nuclear medicine imaging techniques, which provide metabolic and functional information unlike the Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), which provide only anatomical information. However, the combining of SPECT and PET with CT and MRI provides both detailed anatomical and metabolic information [7,8].

To control disease progression before it becomes apparent with conventional morphological imaging techniques or laboratory tests, it is necessary to perform functional molecular alterations *in vivo* by using non-invasive, specific molecular imaging modalities providing anatomical and physiological *in vivo* information [59]. Nuclear medicine offers these molecular imaging methods by observing the body delivery of radiopharmaceutical compounds (gamma and positron-emitters) delivered to the patient and can be visualized by SPECT or PET scanners [60,61].

Cancer treatment and diagnosis

Cancer is a common illness and has been researched extensively. Traditional chemotherapeutic agent treatments have an impact on patients with many toxicity issues because they are not selective to tumor cells. The goal is to find a way to overcome the problem while building a method that can kill cancer cells with therapeutics whereas preventing healthy ones. Nanotechnology has been described as a modern, intelligent technology that creates devices with the potential to deliver drugs to different body locations. Such systems include submicron nanoparticles made up of multiple materials or devices [62].

Nanoparticles have a special property of a high surface-to-volume ratio, enabling different functional groups to attach themselves to a nanoparticle and thus bind to certain tumor cells. The 10 to 100nm small size of nanoparticles, in turn, helps them to be gathered preferentially at tumor sites because tumors lack an adequate lymphatic drainage network. Multifunctional nanoparticles that can diagnose, envision, and then treat a tumor in potential cancer therapy can be produced [63].

Imaging cancer is important for directing treatment plans and measuring the efficacy of the treatments being prescribed. The use of nanoparticles for comparing and enhancing images has allowed traditional modalities such as MRI and ultrasound to enhance cancer imaging and has also created new techniques such as optical-based cancer detection imaging [64]. The treatment's efficacy is specifically tied to the capacity of the medication to attack and destroy cancer cells while keeping healthy cells intact. Consequently, the high degree of cancer cell selectivity would be one of the most significant characteristics of novel anticancer agents. In this field, the convergence of nanotechnology with medicine represents a promising path to improving cancer therapy [65].

Conclusion

To conclude, nanotechnology is a fascinating and quickly evolving aspect of engineering that enables us to interact at the radioactive, and molecular levels to explore, manage, and apply nanometer-dimensional. It has opened up new prospective applications in biotechnology and molecular biology. Nanotechnology has revolutionized nearly all of the veterinary and animal science disciplines specifically in the developed countries by providing in-depth information and showing what is going on inside the deeper body of an organism. Nanoparticles used for disease diagnosis, treatment, delivery of drugs, animal breeding, and reproduction include quantum dots, magnetic nanoparticles, nanopores, polymeric nanoparticles, nanoshells, fullerenes, liposomes, and dendrimers. While nanotechnology is considered one of the big advances now applied in various fields, relative to other sister disciplines, it is still in the early stages of its application to veterinary science. Furthermore, the complexity of the technology to use and its high cost rendered particularly the developing countries to apply the technology in their animal science sector.

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